AD-777 732

AN OCEAN WAVE MEASURING BUOY

SCRIPPS INSTITUTION OF OCEANOGRAPHY

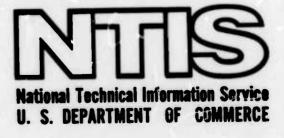
PREPARED FOR

OFFICE OF NAVAL RESEARCH

ADVANCED RESEARCH PROJECTS AGENCY

JANUARY 1974

DISTRIBUTED BY:



REPORT DOCUMENTATION PAGE		BEFORE COMPLETING FORM	
1. REPORT NUMBER	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER	
SIO Meference No. 74-6		AN 777 732	
4. TITLE (and Subtitle)		S. TYPE OF REPORT & PERIOD COVERED	
An Ocean Wave Measuring Buoy		12/15/70-10/31/73	
		Special Technical	
7. AUTHOR(e)		AOEL Report No.56 8. CONTRACT OR GRANT NUMBER(*)	
Robert H. Stewart		N00014-69-A-0200-6012	
9. LERFORMING ORGANIZATION NAME AND ADDRESS		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS	
7.14-453-2000, X2476 Scripps Institution of Ocean University of California, Sa P.O. Box 1529, La Jolla, Ca.	n Diego	NR 294-016	
11. CONTROLLING OFFICE NAME AND ADDRESS		12. REPORT OATE	
Advanced Research Projects Agency		January 1974	
1400 Wilson Boulevard		13. NUMBER OF PAGES 64 pages	
Arlington, Virginia 22209	nt from Controlling Office)	18. SECURITY CLASS. (of this report)	
Office of Naval Research		Unclassified	
800 N. Quincy Street Arlington, Virginia 22217		18. DECLASSIFICATION/DOWNGRADING	
17. DISTRIBUTION STATEMENT (of the obstract entered in Block 20, if different from Report)			
18. SUPPLEMENTARY NOTES		AFR 25 1974	
19. KEY WORDS (Continue on reverse side if necessary	and identify by block number	D.	
Mave Dudy	TIONAL TECHNICAL ORMATION SERVICE Department of Commerce Springfield VA 22151	6-100	
20. ABSTRACT (Continue on reverse elde if necessary and identify by block number)			
We describe the design surface wave-following buoy spectrum of 0.06 to 0.5 Hz of and an angular resolution of 1.5 m (5 feet) in diameter, completely self-contained. ometer mounted on the inner	that can meas ocean waves wi f around 90°. weighs 150 kg Wave height i	ure the directional th an accuracy of 10%, The buoy is disc shaped, m (300 lb), and is s measured by an acceler-	

DD 1 JAN 79 1473 EDITION OF 1 NOV 66 IS OBSOLETE S/N 0102-014-6601

Unclassified

SECURITY CLASSIFICATION OF THIS PAGE (When Date Entered)

by the tilt of the buoy about the gyro's vertical axis, and buoy heading by a gyro stabilized compass. Data from the transducers are digitized and recorded on computer compatible magnetic tape. Wave spectra are calculated from the data by computer. The accuracy of the measurements is verified by calibration in a wave tank, and by the internal consistency of the data.

Disclaimer

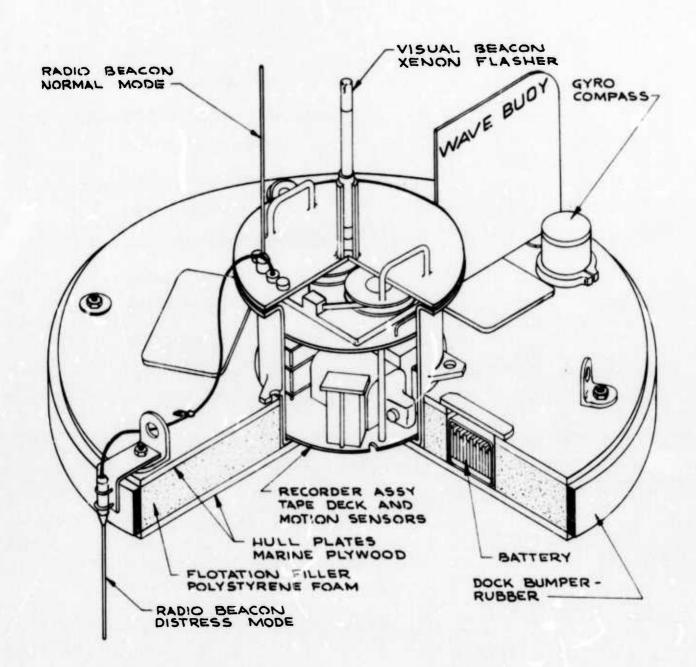
The views and conclusions contained in this document are those of the authors and should not be interpreted as necessarily representing the official policies, either expressed or implied, of the Advanced Research Projects Agency or the U. S. Government.

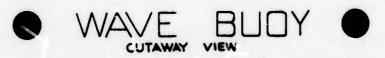
*Amount of Contract: \$3,623,808.00

*Effective date of Contract: December 15, 1968

*Contract Expiration Date: December 31, 1973

*These quantities reflect the cumulative funding of all ARPA-sponsored activities of the Advanced Ocean Engineering Laboratory of Scripps Institution of Oceanography over this 5 year period.





FRONTISPIECE

TABLE OF CONTENTS

		Page
	ABSTRACT	1
1.	INTRODUCTION	1
2.	PRINCIPLE OF OPERATION	3
3.	DESIGN PARAMETERS	7
4.	BUOY CONSTRUCTION	10
5.	DATA ANALYSIS	22
6.	BUOY RESPONSE TO WAVES	25
7.	CONCLUSION	31
	REFERENCES	36
	APPENDIX	38

AN OCEAN WAVE MEASURING BUOY

ABSTRACT

We describe the design, construction, and performance of a surface wave-following buoy that can measure the directional spectrum of 0.06 to 0.5 Hz ocean waves with an accuracy of 10%, and an angular resolution of around 90°. The buoy is disc shaped, 1.5 m (5 feet) in diameter, weighs 150 kgm (300 lb), and is completely self-contained. Wave height is measured by an accelerometer mounted on the inner gimbal of a vertical gyro, wave slopes by the tilt of the buoy about the gyro's vertical axis, and buoy heading by a gyro stabilized compass. Data from the transducers are digitized and recorded on computer compatible magnetic tape. Wave spectra are calculated from the data by computer. The accuracy of the measurements is verified by calibration in a wave tank, and by the internal consistency of the data.

1. INTRODUCTION

The wave measuring buoy described in this report was designed to provide directional spectra of ocean waves for comparison with radar scatter data. Initially we sought to purchase a buoy, but a quick survey of available instruments showed that none were capable of measuring a directional spectrum. Thus we were forced to design and construct one.

A number of techniques exist for determining the directional distribution of a wave field. Essentially, the measurement requires a conerent sample of the wave field over many wavelengths. The directional resolution is proportional to the number of wavelengths used. The measurement of the ocean wave field is particularly difficult because it is difficult to establish a fixed reference point to which wave heights can be related. Wave data can be measured at several places using an array on a stable platform, or, alternately, the surface elevation and two components of slope (tilt) can be measured at one point using an inertial reference.

A buoy that measures wave height and tilt (commonly called a pitch-and-roll buoy) is particularly simple, and can be small and easily handled. We have chosen this technique.

Several pitch-and-roll buoys have been built in the past. The first were designed and built by the National Institute of Oceanography in England. One was contained in a 5 feet 6 inch cast aluminum, ellipsoidal hull (Longuett-Higgins, Cartwright, and Smith, 1963). Later versions used 54" torus shaped hulls. Still later, another version was built by Hudson Laboratories of Columbia University (Saenger 1969a, b; Goldberg and Goldberg, 1969; Jordan, 1969). All of these buoys required a ship to stand by for recording data and supplying power. Our design borrows heavily from these previous instruments and is an

extension of their concept: It is completely self contained and can operate unattended.

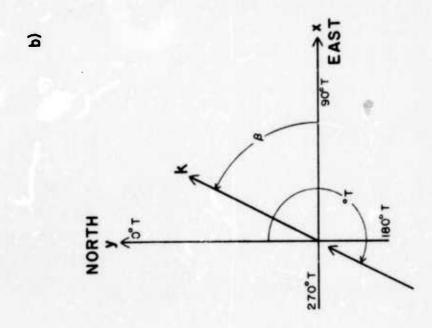
2. FRINCIPLE OF OPERATION

The hull of a pitch-and-roll wave measuring buoy is disc shaped, of shallow draft, and is radially symmetric about an axis normal to the water surface. Such a hull will follow the surface of a wave provided the wavelength is sufficiently long; and its high frequency response will be independent of wave direction. The buoy contains an accelerometer mounted on the axis of a vertical gyro and a gyro stabilized compass. The vertical component of acceleration, when doubly integrated, gives the sea surface height. The buoy tilts, when referenced to the vertical axis of the gyro and to the compass heading, gives the wave slopes in a fixed (North centered) coordinate system. These variables can be related to the ocean-wave directional spectrum and its lower-order moments.

Let

$$(\zeta_1, \zeta_2, \zeta_3) = (\zeta, \partial \zeta/\partial x, \partial \zeta/\partial y)$$
 (2.1)

be the wave height and slopes measured by the buoy as a function of time in a coordinate system with x,y pointing North and East (Fig. 1b). The spectrum $F_i(k_x,k_y)$ of $\zeta_i(x,y,t_0)$ at some instant t_0 is so defined that



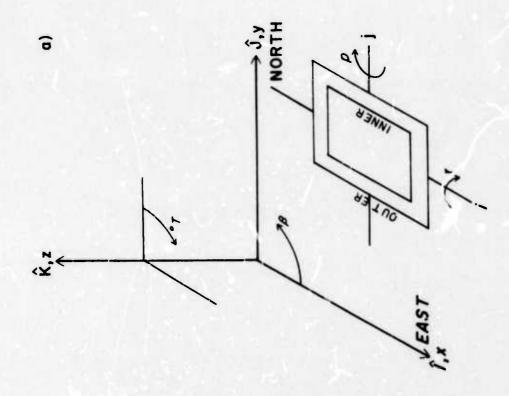


Figure 1. Coordinate system: a) of vertical gyro, b) for analysis of data.

$$\langle \zeta_i^2 \rangle_{\text{space}} = \int_{-\infty}^{\infty} \int_{1}^{\infty} F_i(k_x, k_y) dk_x dk_y = \int_{0}^{\infty} \int_{1}^{2\pi} F_i(k, \beta) k dk d\beta$$
 (2.2)

Similarly, for time series $\zeta_i(x,y;t)$ at one point x_0y_0 ,

$$\langle \zeta_i^2 \rangle_{\text{time}} = \int_0^\infty \int_0^{2\pi} F_i(\omega, \beta) d\omega d\beta$$
, (2.3)

where ω is a radian frequency, k is the wave number. By the ergodic theorem the space and time averages can be equated:

$$F_{i}(\omega,\beta) d\omega = F_{i}(k,\beta) k dk$$
. (2.4)

For deep-water waves, $\omega^2 = gk$, where g is the acceleration of gravity, and the required Jacobian is

$$J = \frac{F_i(k,\beta)}{F_i(\omega,\beta)} = \frac{1}{k} \frac{d}{dk} = \frac{g^2}{2\omega^3} . \qquad (2.5)$$

It is convenient to express all measured spectra in terms of $F_i(k_x,K_y)$, $F_i(\omega,\beta)$, etc., e.g. the contributions (per unit wavenumber space, per unit frequency-radian, etc.) to the meansquare surface elevation. We omit the subscript "i" and refer to F() as simply the wave spectrum.

The Cartesian moments are written

$$M_{pq} = \int_{-\infty}^{\infty} k_{x}^{p} k_{y}^{q} F(k_{x}, k_{y}) dk_{x} dk_{y} = \int_{0}^{\infty} k^{p+q} N_{pq}(k) k dk$$
 (2.6)

where

$$N_{pq}(k) = \int_{0}^{2\pi} \cos^{p} \beta \sin^{q} \beta F(\kappa, \beta) d\beta. \qquad (2.7)$$

For an elementary wave train, the wave height and slope are

$$\zeta_1 = \xi = R e^{i(k \cdot x - \omega t)}$$

 $\zeta_2 = \partial_x \xi = R ik \cos \beta e^{i(k \cdot x - \omega t)}$

 $\zeta_3 = \partial_y \xi = R ik \sin \beta e^{i(k \cdot x - \omega t)}$. (2.8)

The co-spectra C_{ij} and quadrature-spectra Q_{ij} of any pair of quantities ζ_i and ζ_j can be expressed in terms of the moments:

$$C_{11}(\omega) = \int_{0}^{2\pi} F(\omega, \beta) d\beta = J^{-1} N_{00}$$
 (2.9)

$$C_{22}(\omega) = \int_{0}^{2\pi} k^{2} \cos^{2}\beta F(\omega, \beta) d\beta = J^{-1} k^{2} N_{20}$$

$$C_{33}(\omega) = \int_{0}^{2\pi} k^{2} \sin^{2}\beta F(\omega, \beta) d\beta = J^{-1} k^{2} N_{02}$$

$$C_{23} = \int_{0}^{2\pi} k^{2} \cos \beta \sin \beta F(\omega, \beta) d\beta = J^{-1} k^{2} N_{11}$$

$$Q_{12} = \int_{0}^{2\pi} k \cos \beta F(\omega, \beta) d\beta = J^{-1} k N_{10}$$

$$Q_{13} = \int_{0}^{2\pi} k \sin \beta F(\omega, \beta) d\beta = J^{-1} k N_{01}$$

and
$$C_{12} = 0$$
, $C_{13} = 0$, $Q_{23} = 0$. (2.10)

Furthermore, a trigonometric identity gives

$$k^2C_{11} = C_{22} + C_{33} (2.11)$$

Equations (10) and (11) serve to estimate the accuracy of the buoy data.

The five moments determined by the buoy can serve to evaluate the first five Fourier terms of the directional distribution of ocean-wave energy (at each frequency)

$$F^{(5)}(k,\beta) = 1/2 a_0 + a_1 \cos \beta + b_1 \sin \beta + a_2 \cos 2\beta + b_2 \sin 2\beta$$

with

$$(a_0, a_1, b_1, a_2, b_2) = (N_{00}, N_{10}, N_{01}, N_{20}, a_{02}, 2N_{11})$$
 (2.12)

The terminated Fourier expansion can be expressed in the form (Longuett-Higgins, Cartwright, and Smith, 1963)

$$F^{(5)}(k,\beta) = \frac{1}{2\pi} \int_{0}^{2\pi} F(k,\beta) W(\beta'-\beta) d\beta'$$
 (2.13)

where $W = 1 + 2\cos(\beta' - \beta) + 2\cos(\beta' - \beta)$ can be regarded as a weighting function associated with the buoy measurements. When $\beta' - \beta = 0$, $\pm 44^{\circ}$, W = 5, 5/2 respectively. Thus the angular resolution of the tilt buoy can be taken at 88°. This is not very good, but it is the penalty one must pay for having a simple instrument.

3. DESIGN PARAMETERS

The wave buoy was to be used primarily in a trade-wind sea. To meet our requirements it must measure the ocean wave spectrum in the frequency band of 0.06 to 0.5 Hz (2-16 sec period) while wind speeds range up to 15 m/sec. Furthermore, it must be completely self-contained and operate for up to 24 hours unattended.

Typically, we expect to place it in operation and then conduct other experiments nearby. After three or four hours we would return and recover the buoy. The measured spectra should have an error of no more than 10% in amplitude or 10° in direction. These criteria determine the buoy size and transducer accuracy.

To estimate the accuracy required of the transducers using these criteria we assume an ocean wave spectrum proposed by Pierson and Moskowitz (1964)

$$S(\omega) = (\alpha g^2 \omega^{-5}) \exp[-\beta g^4 (v\omega)^{-4}]$$
 (3.1)

where

$$S(\omega) = \int_{0}^{2\pi} F(\omega, \beta) d\beta$$

and v is the mean wind velocity. We use $\alpha = 8.1 \times 10^{-3}$ and $\beta = 0.74$. The acceleration spectrum derived from (3.1) is:

$$S_{\lambda}(\omega) = \alpha g^{2} \omega^{-1} \exp[-\beta g^{4} (v\omega)^{-4}]$$
 (3.2)

The root-mean-square accéleration is:

$$\langle \zeta_{\mathbf{A}} \rangle^{1/2} = (\int_{0}^{\infty} S_{\mathbf{A}}(\omega) d\omega)^{1/2}$$
 (3.3)

This integral diverges because of the contributions at large ω . However, a buoy will respond only to waves whose frequency is less than some frequency, Ω ; its acceleration is found by integrating (3.3) to this upper limit. This gives:

$$\langle \zeta_{A} \rangle^{1/2} = (-\alpha g^{2}/4 E_{i}[-\beta g^{4}(v\Omega)^{-4}])^{1/2}$$
 (3.4)

Here E_i is the logarithmic integral defined by Jahnke and Emde (1945, p. 1). We expect the buoy to respond to waves whose wavelength is roughly twice the buoy diameter or greater (see the end of this section). Waves at the high frequency cut-off typically have a frequency of one Hertz. Letting $\Omega = 2\pi/\text{sec}$, $<\zeta_A>^{1/2}=13\%$ g when v=15 m/sec and 5% g when v=2 m/sec. To measure these accelerations with an accuracy of 10% requires an accelerometer with a total error band of less than 0.5% g over a range of 0-2 g.

The directional spectrum (2.12) is calculated from the slope spectra and co-spectra. The accuracy is limited mainly by the coefficients a_2 and b_2 which depend on the two slope measurements. Each must be measured to an accuracy of $10\% + \sqrt{2}$ if the two components, taken together, are to have a total error of less than 10% on average.

The root-mean-square slope is directly related to the acceleration spectrum through the dispersion relation:

$$\langle \zeta_2^2 + \zeta_3^2 \rangle = k^2 \langle \zeta_1^2 \rangle = g^{-2} \langle \zeta_A^2 \rangle$$
 (3.5)

The acceleration measured in units of g is the slope in radians. A 2 m/sec wind gives an RMS surface slope of 3°, a 15 m/sec wind gives 7°. A vertical gyro capable of measuring these angles to an accuracy of 7% must have an error of less than 0.2° over the band ±30°, the Stokes limit for a progressive wave of maximum amplitude.

The operation of the wave buoy requires a hull which accurately follows the water surface. One that is disc shaped and of shallow draft will perform well until the wavelength becomes less than about twice its own diameter. Since a 2 sec wave has a wavelength of 6.2 meters, the buoy should be somewhat smaller than three meters. On the other hand, it should be easily handled. As a compromise, we arbitrarily chose a hull 1.5 m (5 ft) in diameter, with a draft of about 8 cm.

Such a buoy displaces 150 kgm. Hudson Laborator es' experience with smaller buoys indicated that a hull of this size will survive 15 m/sec winds with only a small chance of being upset (of course it would not be sunk).

We estimate the response of this size buoy hull from Kim (1966). From his figure 11, the half-power point in heave response occurs when $a=R\omega^2g^{-1}=1.5$, R is the radius of the buoy (0.75 m). This occurs at a frequency of 0.7 Hz. In a similar manner, the half-power point in the pitch response occurs when a=3.8 (Kim's figure 12). This corresponds to a frequency of 1.0 Hz. The hull responds to wave slope slightly better than to wave height near t'e cut-off frequency. In either case, the response is within 10% of unity at frequencies of 0.5 Hz and lower, so the hull should meet our requirements.

4. BUOY CONSTRUCTION

The buoy consists of four main systems: 1) the transducers, 2) the signal conditioning and recording system, 3) safety and recovery system, and 4) the buoy hull that houses and supports this equipment. We will discuss each in order. The sources of supply and cost of equipment discussed below, together with detailed electrical schematics, are included in the appendix.

The transducers consist of a vertical gyro, an accelerometer mounted on the inner gimbal of the gyro, and a gyro stabilized magnetic compass.

The gyro-accelerometer assembly was made by Honeywell, and consists of a vertical gyro (part number JG7044A45) and a quartz-fiber accelerometer (GG326Cl). The accelerometer has a range of 0 to 2 g, a total error band of 0.01% g, a drift in sensitivity of 0.02% g/°C, and in zero point of 4 x 10^{-6} g/°C. The gyro gimbal remains vertical to within ± 0.25 °, and has a full scale range of ± 30 °. The tilt of the buoy is measured with a resistance potentiometer having a 1% linearity. The entire assembly is $26 \times 15 \times 14$ cm in size, weighs 4 kgm, and uses about 50 watts of power.

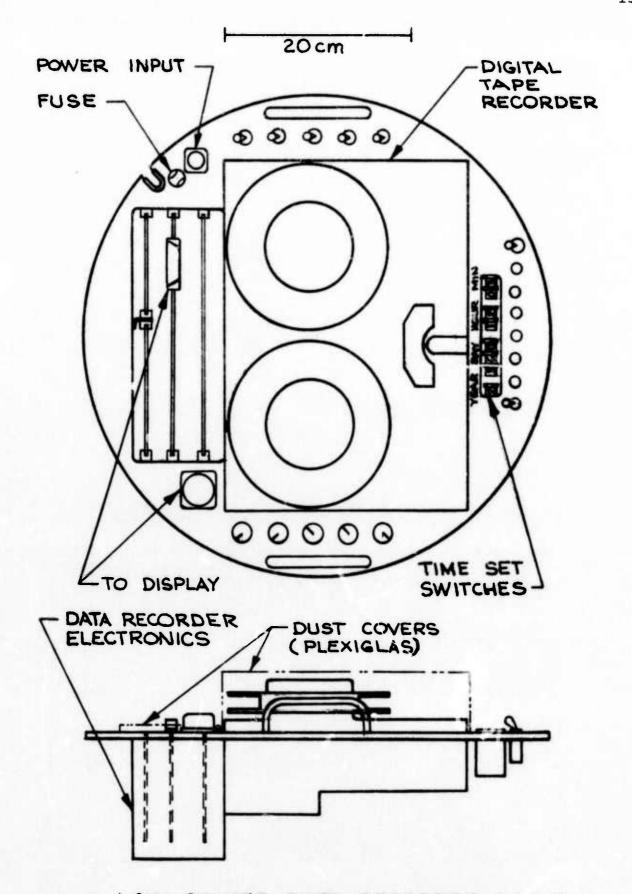
Buoy heading is measured by a Humphrey North Seeking Gyro (DG04-0122-1). This consists of a gyro stabilized and gimbaled magnet whose position is measured by a resistance potentiometer. The unit has an accuracy of $\pm 1^{\circ}$, and is linear within $\pm 1^{\circ}$. Physically, it is 21 x 8 x 8 cm, weighs 1 kgm, and uses 10 watts of power.

The recording system conditions the signals from the transducers, converts them to digital numbers, and records them on computer compatible magnetic tape. In addition, it controls the operation of the buoy, times its operation, and writes the time on the tape. The system was designed and built by Monitor Laboratories. The tape recorder is a standard unit manufactured by Precision Instruments (PI1387). The assembly is remarkably small (see figure 2), and its standby power requirement was less than two watts.

The signals from the transducers vary between ±5 volts, and contain some noise at higher frequencies, particularly at 400 Hz (the frequency of the gyro supplies). To reduce aliasing errors, the signals are sent through low-pass filters. The voltages from the potentiometers (tilts and heading) go through a simple RC filter with a cut-off frequency of 20 Hz. The accelerometer signal is more severly attenuated since it must be integrated twice to obtain sea surface heights. Even a small amount of aliased power could cause severe errors in the measurement of low-frequency wave heights. This signal goes through a two-pole filter with a cut-off frequency of 1.0 Hz. The complex filter response functions are:

$$L = (\omega^{2} - 1)(\omega^{4} + 1)^{-1} + j\sqrt{2}\omega(\omega^{4} + 1)^{-1}$$

$$L = (\omega^{2} + 1)^{-1} + j\omega(\omega^{2} + 1)^{-1}$$
(4.1)



· LOW POWER DATA RECORDER ASSY ·

Figure 2.

where ω is frequency in Hz. Measured responses are very close to values calculated from these equations: within 4% in amplitude and $1/2^{\circ}$ in phase at the half-power frequency.

The filtered signals are multiplexed, converted to 12 bit binary numbers (an accuracy of approximately ±0.01%), and recorded on 1/2" magnetic tape. The recording format is variable and controlled by switches. The correct time (year, day, minute) is recorded at the beginning of each record. The time base was a quartz crystal having an accuracy of ±4 seconds/day over a 50°C temperature range.

A 7 track, incremental tape recorder records the data at a density of 200 characters per inch and at a rate of up to 200 steps per second. It is rugged, can operate with 2 g RMS accelerations, uses one watt of power during standby and 40 watts while recording. The total amount of energy required to write 600 feet of tape is fixed at approximately 7 amp-hours from a 12 volt supply (72 joules). The rate of energy used is determined by the rate data is recorded. Typically, recording 144 bits/second uses 4 watts (144 bits/second = four 12-bit words, three times a second).

The recording system controls the buoy operation. The correct time is entered in the clock by switches. Once started, the system turns on power to the equipment 10 minutes before the next hour, and begins recording on the hour. Data are recorded in the format selected. After the selected amount has been written, recording stops and power is turned off. One,

two, or four hours later the cycle repeats, thus allowing the buoy to operate unattended for a number of hours.

Typically, each transducer is sampled 3.125 times/sec; 2048 samples are written in each record; and 16 records comprise a file. The records contain 10 minutes of data, the file about 3 hrs. Each file uses about 9 meters (27 feet) of tape. Spectra calculated from this data have a resolution of 1.5 x 10⁻³ Hz and a Nyquist frequency of 1.6 Hz. This format ensures that low frequency waves are adequately resolved, aliasing errors are small, and the time series are easily handled in the computer.

Power for the operation of the gyros and recording system comes from sealed, gel-cell, lead-acid batteries. In normal operation the buoy uses 7 amperes at 12 volts. Twenty-four hours of continuous operation requires 168 amp-hours of energy, but intermittant operation reduces this considerably. The buoy has six 20 amp-hour batteries. They operate in any position, and need not be protected from sea water. Each battery is isolated by diodes: failure of one does not affect the operation of the others. The batteries weigh 48 kgm and are a major part of the buoy weight, but are small in size (0.02 m³).

The 12 VDC power is converted into other voltages required by the systems (see figure 3). The gyros operate from 115 and 26 VAC, 400 Hz. The first voltage is produced by a switched inverter (Nova). Switching transients occur on the 12 VDC lines and are reduced by the input and RF filters. The 26 VAC is derived from a transformer. A small amount of ±15 and +5

CIARA

FLOW

POWER

AND

SIGNAL

पु

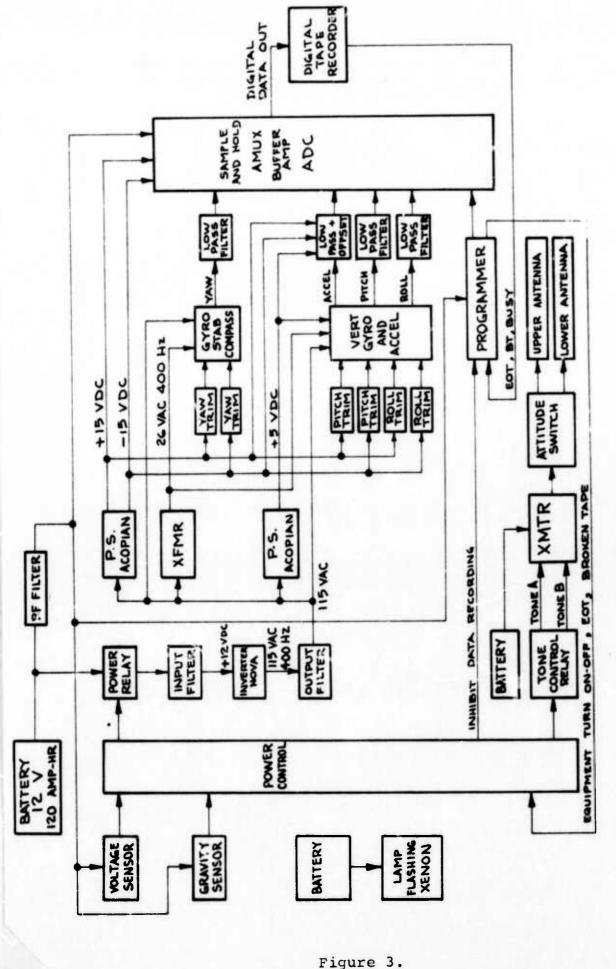


Figure 3.

VDC is produced by two Acopian power supplies. This serves the potentiometers, accelerometers, and data recorder.

The buoy is designed to operate unattended, consequently it has systems that help in finding it once it is out of sight. It also recognizes and responds to certain dangerous conditions such as overturning in large seas. In this event, the gyros tumble and no data can be obtained. Other mishaps include loss of power (batteries discharged), broken magnetic tape, or end of tape. The occurrence of any of these events turns off the power to the gyros, terminates the recording of data, and causes the buoy to call for help on its radio.

To aid in finding the buoy, it is painted bright yellow, has a flashing zenon light, and a citizen band (27 MHz) radic transmitter. The buoy can be seen for several hundred meters in 2 meter seas. The flashing light can be seen for one kilometer at night. The radio can be heard from 10 km away. The transmitter sends out 500 m watt pulses and has two antennas, one on top and one on the bottom of the hull. In the event of a mishap the pulse rate doubles. If the buoy overturns, the bottom antenna is activated. The antennas are small (40 cm long) and are not likely to be damaged while the buoy is handled. Both the light and the radio have their own batteries; both can operate for two days.

In typical operation, the buoy is started, and placed in the water. Some time later it starts and data is recorded. It

is difficult to stand around hoping all is well. To aleviate distress in the operators, the buoy has a small (100 m watt) citizen-band radio transmitter that transmitts everything it hears. The operators, several hundred yards away can hear the gyros turn on and spin up, and can hear the tape recorder step each time data is recorded. This verifies that all is well, and the operators are relieved.

The general layout of the buoy hull is shown in the cutaway view (frontispiece) and figure 4. The control logic, vertical gyro, inverter, and transmitter are mounted together on a
frame (figure 5). The data recorder (figure 2) mounts directly
on top of this. The entire assembly is housed in a watertight
aluminum can. The light and transmitting antenna are mounted
on top of this. The north-seeking gyro (in a waterproof polyvinylchloride container) and the batteries mount on the buoy
hull. Underwater type connectors connect them to the lid of
the can. The container is 52 cm in diameter, 40 cm high, and
weighs 60 kgm.

The hull is made of two, 1.5 meter (5 feet) diameter sheets of 1" marine plywood. Ten centimeters (4 in) of closed-cell styrofoam is sandwiched between them for floatation, and the three bolt together to form the hull. The aluminum can and gyro bolt into holes in the top piece of wood. The batteries are held below three hatch covers. All wiring is routed between the plywood sheets and protected. A small wind vane provides

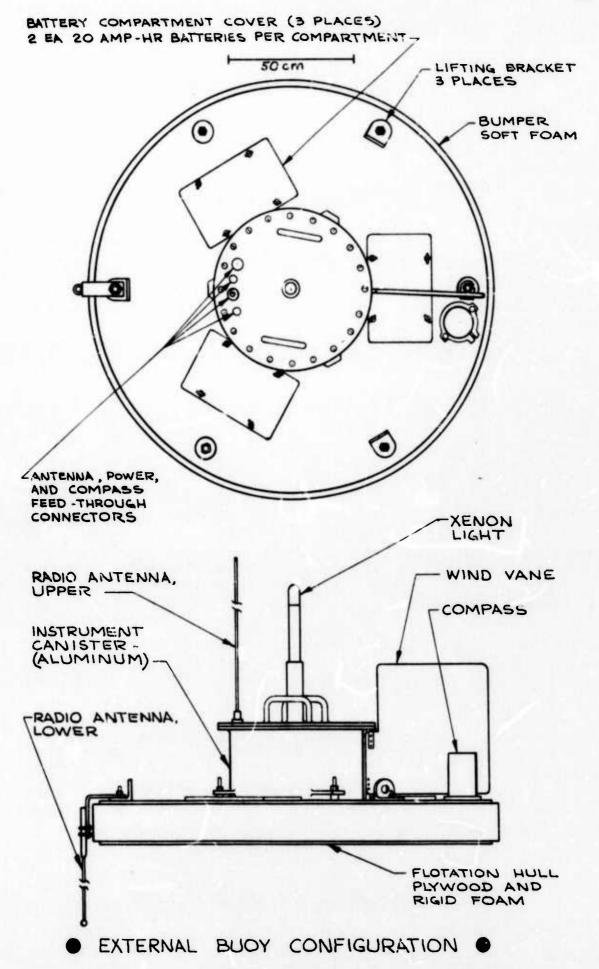
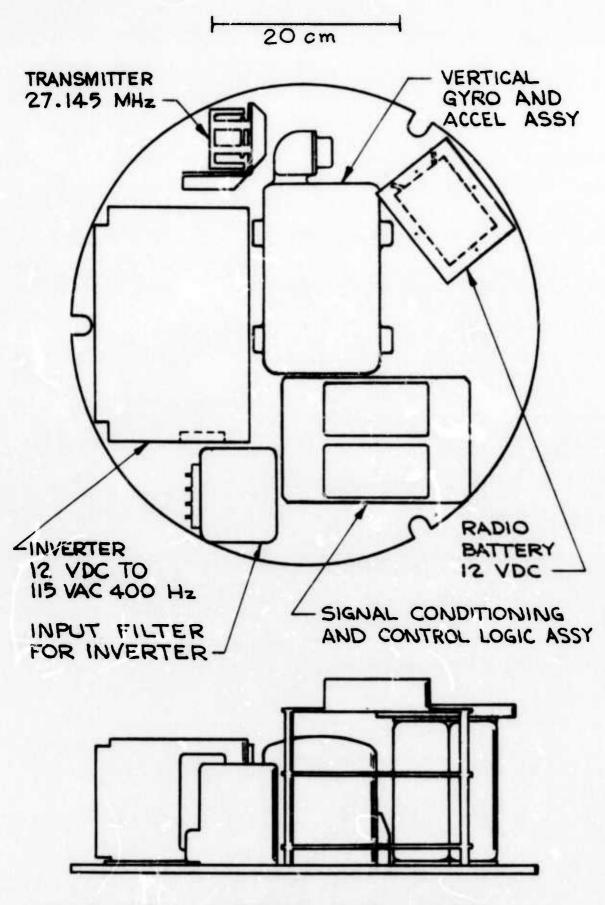


Figure 4.



• EQUIPMENT MOUNTING PLATE ASSY •

further protection for the compass gyro. The edge of the hull has a soft neoprene bumper glued to the styrofoam.

The entire buoy assembly bolts together. The aluminum can is easily removed and carried into a protected laboratory for repairs, calibration, and setting switches for turning on the electronics. The electronic rack may be unplugged and removed. All electronic components, gyrcs, etc., plug ir and can be removed for repair. Connections to the data recorder are by screws on a terminal strip. All internal wiring is laced together. Thus the entire assembly may be quickly and easily disassembled for repairs. In normal operation, the unit can be switched on, the lid to the aluminum can bolted on, the can bolted into the hull, and the buoy launched, all in 20 minutes, by three people.

A three-point bridle of spliced 3/4" nylon rope is attached to the buoy for launching. Usually, 30 meters of 3/4" polypropylene rope is attached to the bridle. When the buoy is in the water, this line floats on the surface upwind of the buoy. The heavy line is necessary to handle the buoy in rough seas.

A smaller line (1/2") parted during one recovery.

The aluminum can and wind vane are painted bright yellow (epoxy coating). The hull is bright red. English and Japanese lettering on the vane identifies the buoy. External fittings are stainless steel, external wiring is neoprene jacketed. This greatly reduces corrosion and electrical shorts to sea water.

5. DATA ANALYSIS

The buoy data are analysed on a Burroughs B6700 computer. A complete listing of the program is produced in the appendix. Although it appears long and complicated, it is, in fact, straightforward. Processing of data is quick, typically one hour of buoy data is analysed in 11 minutes at a cost of about \$25. The following paragraphs outline the procedure, shown graphically in figure 6.

Data from the four sensors (acceleration, two tilts, heading) are written on magnetic tape as six-bit characters. The first 24 bits of each record is a time word. The procedure TAPESTART positions the tape at the record to be read, and notes any read errors in records passed over. The procedure READTAPE transfers into the computer the bits written in a particular record, converts them into time series with appropriate units, removes the mean, and notes any apparent errors. Procedure PRDATE decodes the first 24 bits into time and date. The four time series are transformed into the frequency domain (using the Fast Fourier Transform) by the computer's library routines FFT and BITRV2.

The frequency data are multiplied by the appropriate inverse filter function L^{-1} calculated from (4.1). Some data were recorded with sample-and-hold modules installed in the data recorder. In this case, all channels were sampled simultaneously. Other data were recorded without the modules and the chan-

DATA AMALYSIS FLOW CHART

Ŋ

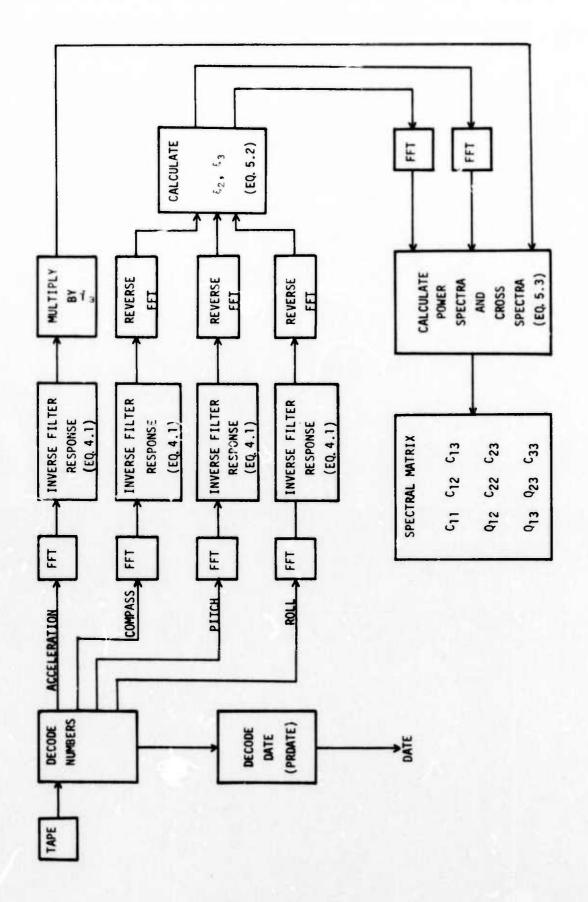


Figure 6.

nels were sampled sequentially. This is equivalent to applying the linear filter:

$$L = \cos n\omega \tau + j\sin n\omega \tau \tag{5.1}$$

where n = 0,1,2,3 is the order of sampling, and τ is the time delay between samples. When appropriate, the inverse of this filter was applied. Finally, the tilt and heading were transformed back into the time domain.

At this point, the slopes are relative to the buoy, and must be transformed into a geographic coordinate system. Let r be the rotation about the outer gimbal axis, p the rotation about the inner gimbal axis, and °T the angle measured clockwise from North to the inner gimbal axis in the coordinate system shown in figure la. The coordinate transformation is

$$\zeta_2$$
 = (-sin°T/cos p)tan r + cos°T tan p
 ζ_3 = (-cos°T/cos p)tan r - sin°T tan p (5.2)

These equations follow from Saenger's (1969) equations (9.6) for $\psi = 270^{\circ}$ and $\psi = 0^{\circ}$, and noting $m = -^{\circ}T + 90^{\circ}$.

The slope series are transformed back into the frequency domain and the appropriate Co- and Quadrature-spectra are computed from the Fourier coefficients of the data using:

$$2C_{ij} = a_i a_j - b_i b_j$$

 $2Q_{ij} = a_i b_j + a_j b_i$ (5.3)

where a_i , b_i are the cosine and sine transformation of the first series, a_j , b_j are those of the second series. Note that the sign of Q_{ij} is arbitrary. Our definition agrees with (2.9), but is in disagreement with the convention used by some workers.

The spectral quantities (2.9) are used to calculate various parameters of the ocean-wave directional spectrum. The mean wave direction (at each frequency) is:

$$\tan \beta_0 = N_{01}/N_{10} \tag{5.4}$$

The root-mean-square beamwidth can be calculated several ways; we use

$$\tan 2\gamma = \left(\frac{1-R}{1+R}\right)^{1/2} \tag{5.5}$$

where

$$R^{2} = [(N_{20} - N_{02})^{2} + 4N_{11}^{2}]/N_{00}$$
 (5.6)

This agrees with equation (22) in Longuet-Higgins, Cartwright and Smith (1963).

6. BUOY RESPONSE TO WAVES

We have estimated the response of the buoy to waves by observing the internal consistency of data recorded at sea and by calibration in a wave tank. In general, the buoy responds as a damped harmonic oscillator with a 1/2 power point near

0.7 Hz. The accuracy of the data meets the design criteria specified in section 3.

Before describing the calibration of the buoy, we first give a gross overview of some typical data. They were obtained off Monterey, California in a 10 m/sec wind when the significant wave height $(4<\zeta^2>^{1/2})$ was 2.5 m. A short section of the digitized data from the four transducers (figure 7) indicate the general range of these variables. The root-mean-square acceleration was 10.3% g, and the slope was 6.8°. This is in very good agreement with the values of 10.7% g and 6.1° predicted by eqs. (3.4) and (3.5) using $\Omega=0.7$ and $\nu=10$ m/sec.

The first time the buoy was operated at sea we sampled the transducers at the maximum possible rate to determine the optimum rate for later operations. The Nyquist frequency (maximum frequency of the digital spectrum) was 6.25 Hz. The acceleration spectrum recorded on this occasion is shown in figure 8. The noise at low frequencies has a spectral power of around 10 cm²sec⁻⁴Hz⁻¹. The high-frequency noise is considerably lower, and the Nyquist frequency could be reduced considerably. Consequently, all later data were recorded with a Nyquist frequency at 1.5625 Hz (each signal was sampled 3.125 times per second).

The spectra derived from the Monterey data are plotted in figure 9. The Nyquist frequency is 1.5625 Hz, the resolution is 0.0015 Hz. The figure gives a good indication of the signal/noise ratio of the data. The acceleration values are approxi-

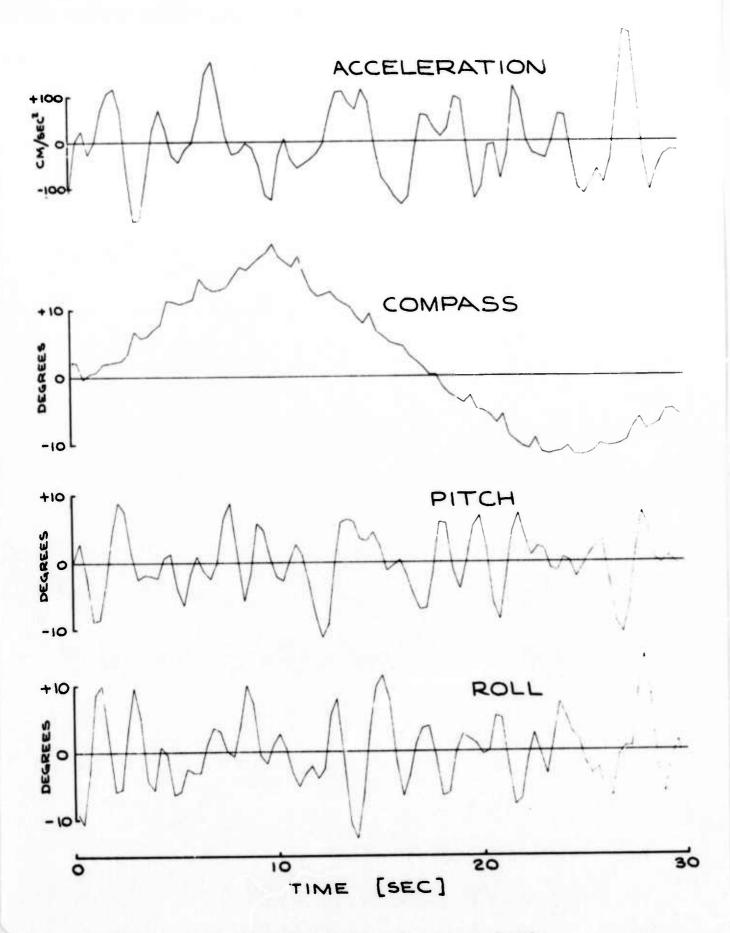
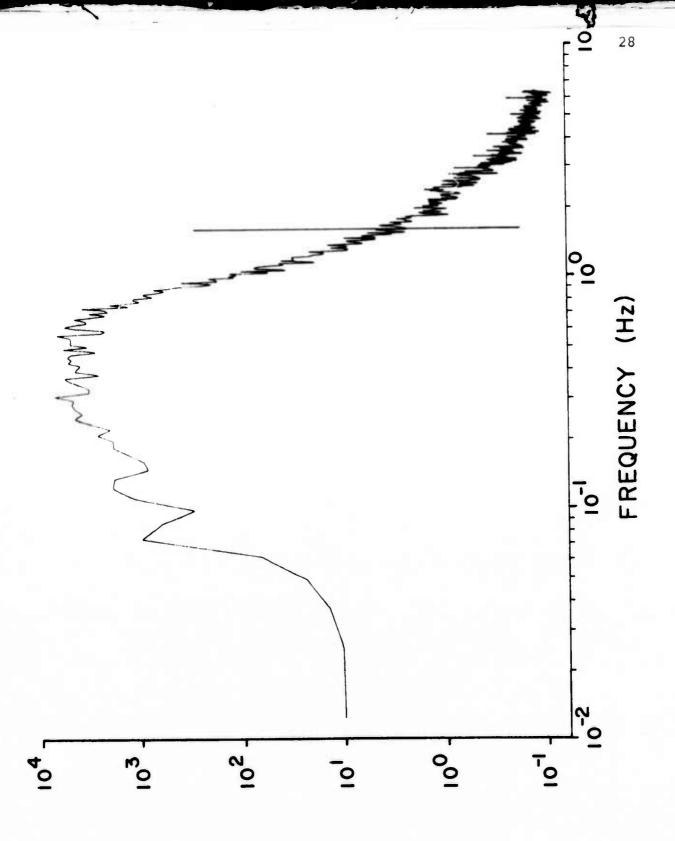


Figure 7. Typical time history of analog signals.



(CM² SEC-4 Hz-1)

ACCELERATION SPECTRUM

Figure 8. Acceleration spectrum with 6.25 Hz Nyquist frequency. Vertical line is at 1.5625, the Nyquist frequency used for subsequent recordings.

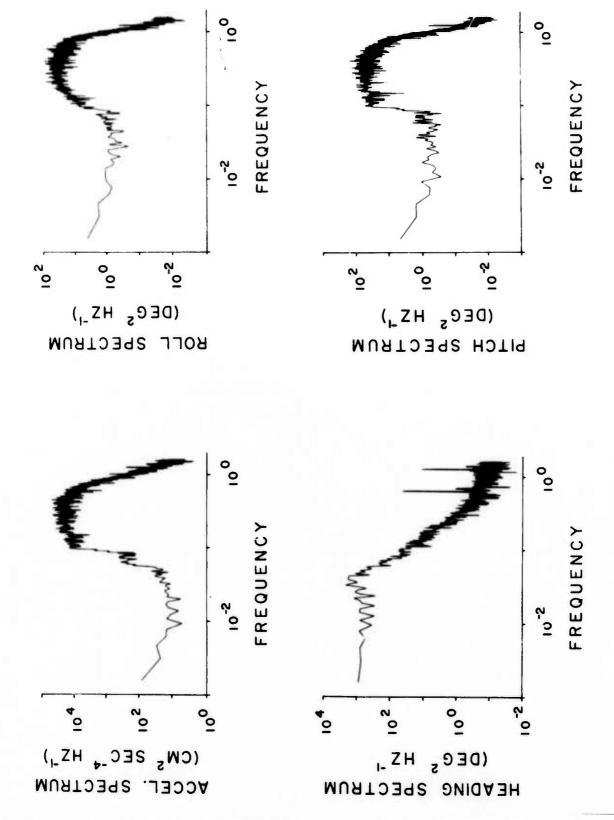


Figure 9. Typical spectra of acceleration, pitch, roll, and compass heading, as a function of frequency in Hz.

Nyquist frequency is at 1.5625 Hz. Each spectrum has two degrees of freedom.

\

mately 1000 times the low-frequency noise, and the low and high frequency ends of the spectrum are identical to those in figure 8. The slope spectra are approximately 100 times larger than the low-frequency noise. The slight rise in energy near zero frequency is due to drift in the sample-and-hold modules, and is the reason for not using them on subsequent days. The buoy heading swings slowly with time, so its spectrum is large at low frequencies. The small spikes in the spectrum are due to aliased 400 Hz noise.

The acceleration noise values require some comment. The noise is 30 times that expected from least count noise (which itself is about equal to the noise from the transducer). It is also about 30 times larger than the noise measured with the instrument on land (no motion). It is probably due to the slightly non-linear way the buoy responds to the motion of the sea, and is not significant for our work. For example, a sinusoidal wave with an amplitude of 0.8 cm at the lowest frequency of interest (0.06 Hz) is detectable with a signal/noise ratio of one. The contribution to this same frequency band by a fully developed sea is 100 times larger.

The buoy was calibrated by observing its response to sinusoidal waves in a tank 2.6 meters wide, 2 meters deep, and 30 meters long. This facility is just barely adequate; fortunately, the best data was obtained near the buoy cut-off frequency. Lower frequency waves were too long for the shallow tank, and shorter waves were not two dimensional. The observed response is plotted in figure 10, together with the

response of a 1/8 ellipsoidal hull calculated by Kim (1966). Although this hull is not very similar to the buoy in plan view, it has nearly the same cross-section along one axis, and it is of shallow draft. The wavenumber k of the incident waves was calculated from the wave frequency ω using $\omega^2 = gk$ tank kh, where h is the depth of the water. The figure indicates the model accurately predicts the 1/2 power point in the buoy's response, and the ratio of pitch to heave response at low frequencies. This ratio diverges from the observed values at high frequencies.

We estimate the internal consistency of the data by observing how well eqs. (2.10) and (2.11) are met. In general, C_{12} , C_{13} , and Q_{23} are zero within the statistical fluctuations of the data. Six hours of data recorded in a trade-wind sea, when averaged to give spectral estimates with over 2000 degrees of freedom, yields values for these quantities that are less than 5% of the leading terms (C_{11}) . To evaluate (2.11) we have averaged together 17.23 hours of data and plotted it in figure 11. The peak near 0.9 Hz is predicted by Kim (cf. figure 10), but the slight rise above unity (near 0.5 Hz) is unexplained. Perhaps it is due to the additional moment of inertial of the high instrument can.

7. CONCLUSION

The wave buoy has worked well. Typically we work near shore. The buoy is taken 20-30 km offshore, data is collected

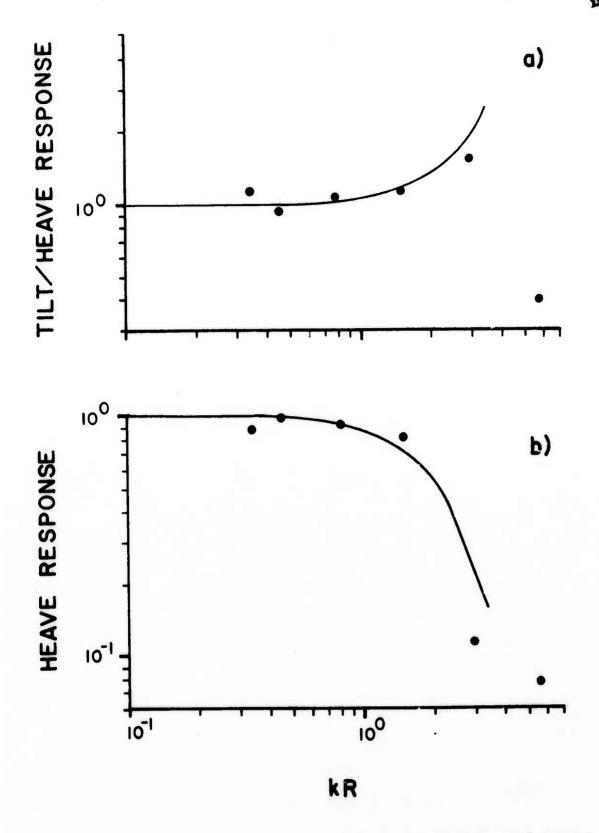


Figure 10. Measured response of buoy to wave tunnel waves (solid points) compared with Kim's (1966) theory (solid line); k is the wavenumber of the waves, R is the buoy radius. a) measured slope/(k·measured amplitude). b) measured amplitude/amplitude of waves.

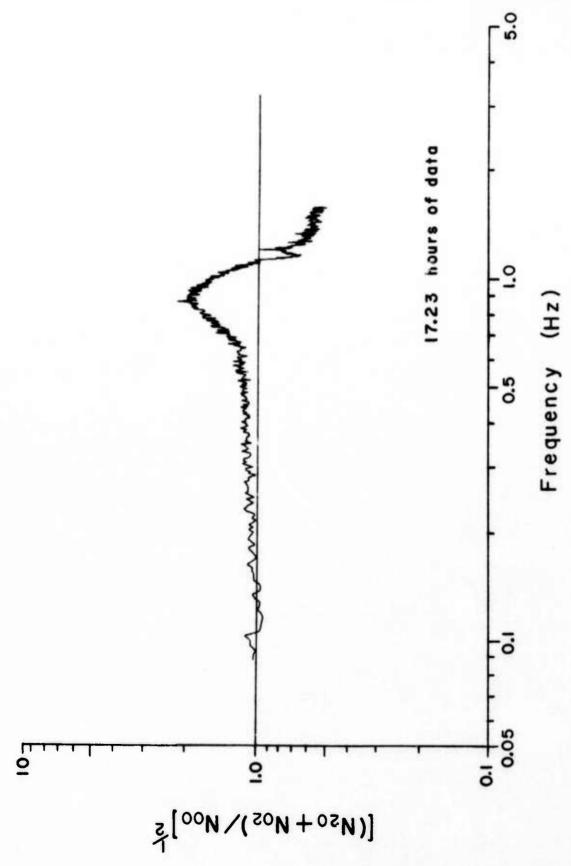


Figure 11. Ratio of wave slope to wave amplitude (times k) calculated from 17.23 hours of data recorded at sea.

for three hours, and we return, all in one day. In one year, it has operated at sea on nine different days in four different parts of the world and recorded more than 30 hrs of data. During this time there was only one major failure. On the last day of operation the unit stopped because of low battery voltage. Inspection revealed sea water had corroded away most of the terminals and discharged the batteries.

The data recorder has also worked well. We usually record data in 10 minute segments (records) of 2048 scans. Out of over 200 records recorded, 5% (11 records) have errors. All but two are due to the tape recorder adding an extra 6 bit character in the middle of a record. This is not serious because the data can be recovered with a Little extra computer work. We prefer to ignore these records. Once the clock failed to act properly. No data was lost but the time word was incorrect. Once the record was too long. We suspect these errors were due to noise introduced into the logic circuits by strong radar signals from ships used to deploy the buoy. Certainly, the errors were less frequent when the ship did not have a radar or was not close to the buoy.

The buoy has withstood rough handling. It has been shipped from San Diego to Monterey and back, to San Clemente Island and back, to hawaii and Wake Island. The waterproof connectors have been damaged by inexperienced crane operators on the ships, and the radio antennas have been bent. These items are easily

repaired. The internal components, which are harder to repair, have not been damaged.

The buoy has been deployed by helicopter and from a variety of very small ships with little difficulty. Two men holding lines attached to the bridle mounting points can steady its motion on a rolling ship. It can be lifted by small hydraulic hoists or cranes found on many small workboats, and an inexpensive two-man helicopter can carry it to sea.

Our experience with the buoy shows ways it can be improved. The instrument can could be considerably smaller. It was originally designed to hold the compass, but iron in the inverter caused interference. If only three hours of data are recorded at one time, the much cheaper, low-power, cassette type data recorders could be used. This would make changing tapes easier, and would further reduce the size of the instrument can. Thus the buoy would be more disc shaped, and should have a better response to waves.

In conclusion, we can say the buoy has met the design criteria specified before it was built, and has provided the ocean wave spectra we need in our research program.

REFERENCES

- Goldberg, H. D. and Goldberg, Milton J. 1969 Transducer instrumentation for surface wave measurements. Hudson Laboratories of Columbia University Technical Report 180, Dobbs Ferry, New York.
- Jahnke, E. and Emde, F. 1945 Tables of Functions with formulae and curves. Dover, New York.
- Jordan, W. N. 1969 Mechanical design, construction, calibration and field deployment of surface wave floats. Hudson Laboratories of Columbia University Technical Report 171, Dobbs Ferry, New York.
- Kim, W. D. 1966 On a free-floating ship in waves. Journal of Ship Research, 10, p. 182-191.
- Longuett-Higgins, M. S., Cartwright, D. E., and Smith N. D.

 1963 Observations of the directional spectrum of sea
 waves using the motions of a floating buoy, in Ocean
 Wave Spectra. Prentice-Hall, Englewood, New Jersey.
- Pierson, W. J. and Moskowitz, L. 1964 A proposed spectral form for fully developed wind seas based on the similarity theory of S. A. Kitaigorodskii. J. of Geophy. Res., 69, p. 5181-5190.
- Saenger, R. A. 1969a Measurement of the statistical properties of the ocean surface with instrumented surface floats.

 Part 1: Theory of measurement. Hudson Laboratories of Columbia University Technical Report 183. Dobbs Ferry, New York.

Saenger, R. A. 1969b Measurements of the statistical properties of the ocean surface with instrumented surface floats. Part 2: Engineering and data processing. New York University School of Engineering and Science Technical Report TR-69-10. University Heights, New York.

APPENDIX

This section contains many of the details necessary to operate the buoy and to analyse the data from it. We have included detailed circuit schematics (figs. Al, A2, A3), program listings, and a list of major components and their source of supply.

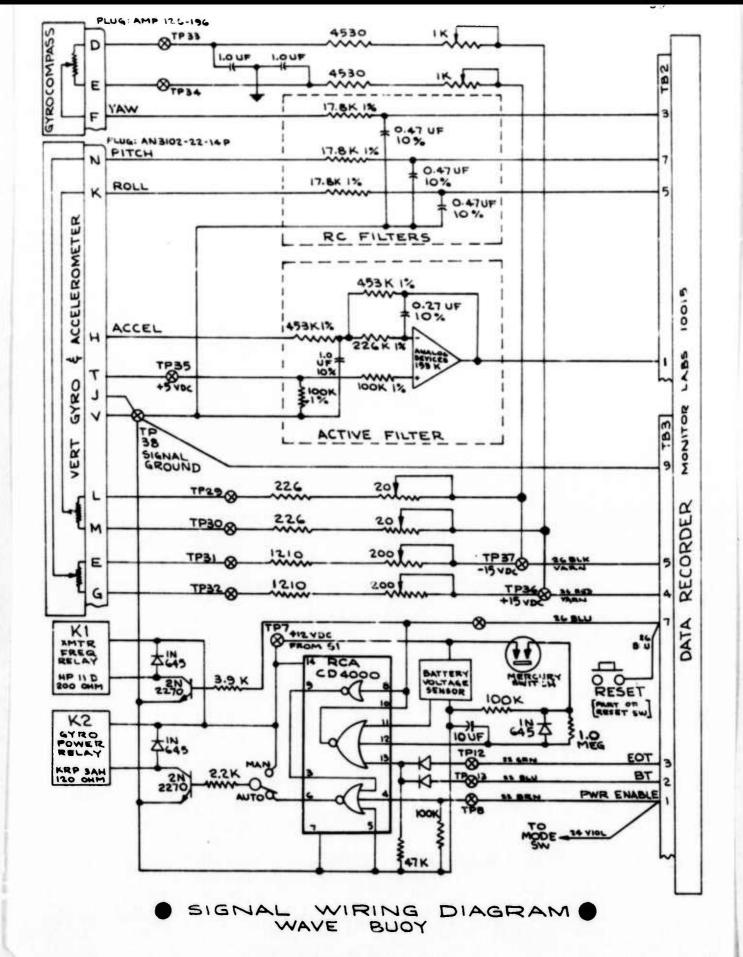
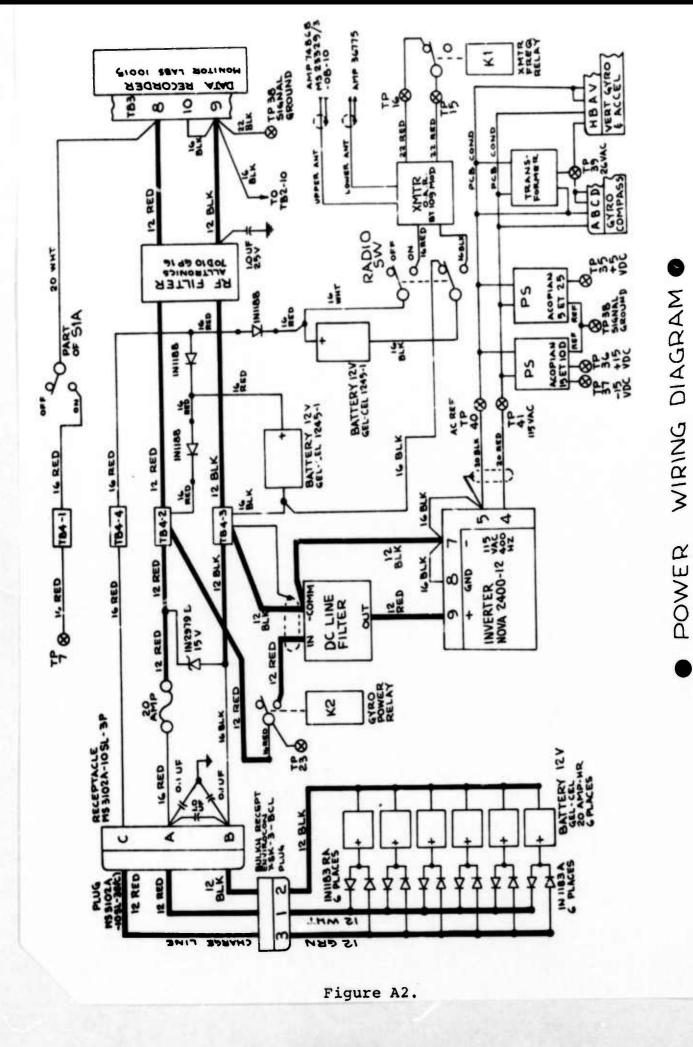


Figure Al.



BUOY

WAVE

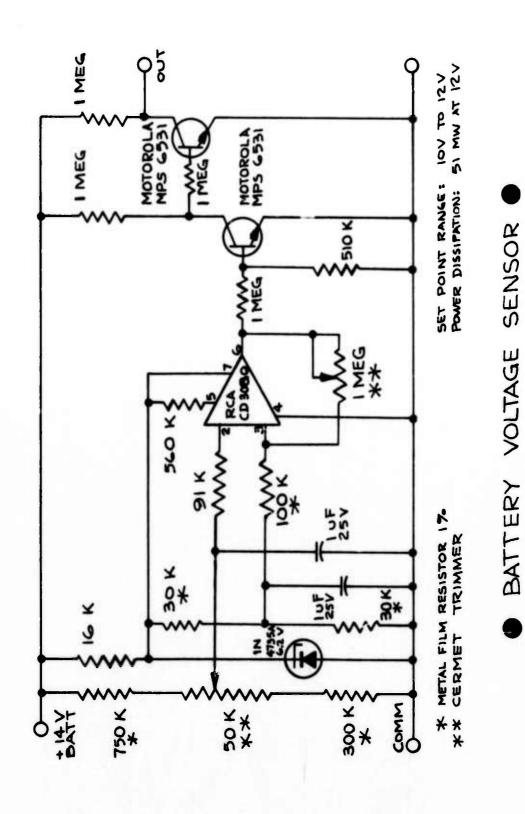


Figure A3.

Listing of Computer Program used to Reduce Buoy Data

0:0000:0 ILCIN BLOCK IS SECTENT ORDER nn2:nnn():f 012:0000:0 PROGRAM WAVEBURY PROVIDES A MEANS OF COMPUTING ESTIMATES OF THE DIRECTIONAL SPECTRUM OF OCEAN WAVES FROM DATA TAPES nn2: 0000:0 nn2:0000:0 002:0000:11 GENERATED BY THE S. I. U. SURFACE-FOLLOWING WAVEBUDY. nn2:6600:6 THE CARO INPUT PARAMETERS TO BE SUPPLIED AME: CARD 1, THE TAPE REEL NAME (6 CHARACTERS); CARD 2, THE TIME-SERIES LENGTH, 2**MEX, FOLLOWED BY THE NYQUIST FREQUENCY IN HERTZ. CARD 3 CONTAINS FIVE 0.1:01:01:10 nn2:nnnn:n nn2:6006:0 INTEGER CONSTANTS VIZ., THE FILE NO. OF THE DATA, THE FIRST RECORD OF THE DATA TO BE USED, THE NUMBER OF RECORDS TO BE AVERAGED, AN INTEGER VARIABLE, "CHANNELS", WHICH SELECTS WHICH OF THE FOUR DATA CHANNELS ARE TO BE USED. IF ALL CHANNELS ARE REQUIRED, AS IN COMPUTING DIRECTIONAL SPECTRA, THEN SET CHANNELS==1111 (BINARY) = 15 (DECIMAL). FOR INSTANCE, IF ONLY CHANNEL 1 POWER SPECTRUM (VERTACLE PATION) CONVENTED TO SUPPLICE ELEVATION) THEN SET =1000 002:0010:3 nn2:0000:0 102:0010:1 (02:000:0 002:0010:1 002:0000:0 nn2:nnna:n 002:0000:0 (BINARY) = 8 (DECIMAL INPUT VALUE). "AVEFQ" IS THE NUMBER OF FREQ. BANLS AVERAGEL OVER AFTER THE AVERAGING OVER SPECTRA FROM 0.62:0066:0 UU.Z:0070:1 INDIVIDUAL RECORDS HAS BEEN DONE. THE NEXT CARD READ IMPUTS: A BOOLEAN VARIABLE "LAV" WHICH, IF SET TRUE, DOES A LOGRITHMIC TYPE nr2:nr.nn:n nn2:nnn1:1 AVERAGING OVER SPECTRAL BANDS (CAUTION: IF LAV=TRUE, SET AVSFQ=1), A HOOLEAN VARIABLE "SAHIN", WHICH IF SET TRUE MEANS THAT THE SAMPLE AND HOLD MODULES OF THE WAVEBUOY WERE OPERATIONAL AT THE nn2:0600:0 002:0000:0 TIME OF CATA COLLECTION: THE MACHEUT WERE OPERATIONAL AT THE TIME OF CATA COLLECTION: THE MAGNETIC COMPASS DEVIATION FRUE TRUE NORTH AND EITHER "F" OR "A" CHARACTER FOLLOWING: "ILIM" IS THE GREATEST WAVE PERIOD TO BE INCLUDED IN FINDING THE VARIANCE; IF BLANK THIS IS AUTUMATICALLY SET TO 2**(MEX-1)/NYQJIST, THE LONGEST PERIOD FOR THE TIME SERIES LENGTH. FINALLY, THERE IS A CARD WHICH CONTAINS SIX HOGLEAN VARIABLES SPECIFYING WHICH TABLES ARE 002:0000:0 002:0000:3 002:0000:0 na2:0010:1 nn2:(infin:n nn2:00cn:0 Ł nn2:na77:a TO BE PRINTED OUT AND WHICH TYPE(S) OF SPECTRA ARE TO BE PUNCHED. 002:0000:0 THIS PROJECT UTILIZES THE "SSET INSALLATION" CONTROLL CARD IN ORDER TO ACCESS THE SYSTEM INTRINSICS: FFT, EITRV2, FFTR, SINCOS. 112:0030:0 002:0000:0 na2:nnan:n 002:0000:0 JOE JOY , PAUL HANSEN BOR STEART nn2:nnnn:n 002:0000:0 APRIL, 1973. nn2:n01n:1

nn2:nnnn:0

```
FILE PRINTER(KIND = 6, MAXRECSIZE = 22);
                                                                                                                                                                                                                        002:0000:0
DATA IS 0005 LONG
  FILE CARD (KIND = 9, MAXRECSIZE = 14);
                                                                                                                                                                                                                                    002:0000:0
                                                                                                                                                                                                                        DATA IS 0005 LONG
  FILE PUNCHER (KIND * PUNCH, MAXRECSIZE = 14);
                                                                                                                                                                                                                                    002:0000:0
                                                                                                                                                                                                                       DATA IS 0005 LONG
  EOOLEAN ERR:
                                                                                                                                                                                                                                    002:0000:0
 INTEGER CHANNELS, FIRSTREC, J, K, LASTREC, MEX, N, NM1, NCHANNEL, NN, NFILE, REC, NWORDS, NREC, TAPENAME, AVEFQ:
                                                                                                                                                                                                                                    002:0000:1
                                                                                                                                                                                                                                     002:0000:0
 REAL FSTEP, OMEG, SCALE, VARN, X, XNYQUIST; REAL ARRAY CAL, MEAN[1:4];
                                                                                                                                                                                                                                    002:0000:0
                                                                                                                                                                                                                                    002:0000:0
  LEFINE PI = 3.1415926535897932W:
                                                                                                                                                                                                                                     002:0002:1
                                                                                                                                                                                                                                    002:0002:1
        NGTE: 3777 OCTAL = 2047 DECIMAL = +5.0 VOLTS. 4000 (FILL CAL[*] WITH .478515625 % (980 CM/SEC ** 2)/2048. ,.001533980768 % PI/2048. ,.000383495197 % (PI/4)/2048. ,.000383495197;% (PI/4)/2048.
                                                                                                                                       4000 OCTAL=2048
                                                                                                                                                                                                                                    002:0002:1
                                                                                                                                                                                                                                    002:0002:1
                                                                                                                                                                                                                                     002:0003:5
                                                                                                                                                                                                                                     002:0003:5
                                                                                                                                                                                                                                    002:0003:5
  REAL(CARD, < A6>, TAPENAME);
                                                                                                                                                                                                                                     002:0000:3
 READICARD, < 14, F10.4>, MEX, XNYQUIST);
READICARD, <513>, NFILE, FIRSTREC, NREC, CHANNELS, AVEFQ);
IF AVEF2 LE2 0. THEN AVEFQ:=1;
                                                                                                                                                                                                                                    002:0014:5
                                                                                                                                                                                                                                    002:0025:2
                                                                                                                                                                                                                                    002:0038:5
 WRITE(FRINTER, <"TAPE REEL=", A6>, TAPENAME);

WRITE(FRINTER, <"MEX=", I3, X5,"NYGUIST=", F8.4," HERTZ.">, MEX, XNYGUIST);

NJORDS:= 0 & 1[MEX: 0:1]; % 2 ** MEX
                                                                                                                                                                                                                                    002:0030:4
                                                                                                                                                                                                                                    002:014B:5
                                                                                                                                                                                                                                    002:0358:4
         N := NWORDS DIV 2 + 1;
                                                                                                                                                                                                                                    002:0050:1
         111 := N -1:
                                                                          SCALE: = 2. / WORDS * 4 2:
                                                                                                                                                                                                                                    002:005F:0
                                                                                                                                                                                                                                     002:0063:2
         #RITE(PRINTER, <"FILE NO. =", 13," BEGINNING WITH RECORD NO. ", 13,
" TOTAL NO. OF RECORDS READ=", 13,
                                                                                                                                                                                                                                    002:0753:2
                                                                                                                                                                                                                                    002:0065:1
                     CHANNELS=", 13>, NFILE, FIRSTREC, NREC, CHANNELS);
                                                                                                                                                                                                                                    002:0055:1
002:0077:1
 1
                                                                                                                                                                                                                                    002:00/7:1
                                                                                                                                                                                                                                    002:0077:1
                                                                                                                                                                                                                                    002:0077:1
                                                                                                                                                                                                                                    002:0077:1
 BEGIN
                       002:00/7:1
                                                                                                                                                                                                                                    002:0077:1
                                                                                                                                                                                                                                    002:0077:1
                                                                                                                                                                                                                                    002:0077:1
 BOOLSAN SAHIN, TABLEL, TABLEZ, TABLEZ, PUNCHKS, PUNCHPS, PUNCHDS, LAV:
                                                                                                                                                                                                                                    002:0077:1
                                                                                                                                                                                                          BLOCK IS SEGMENT 00305
 INTEGER EAST, EORW, ENDPT, FREEDOM, VALAVEFQ, WEST;
                                                                                                                                                                                                                                    005:0000:0
REAL C, C11, C33, C44, C34, C05AZ, C05PITCH, K2, K1, MAGDEV, Q13, Q14, KR, SINAZ, TLIM, TANPITCH, TANROLL, Y, ZETA, Z;

PEAL NZERO, DENOM1, DENOM2, JACOBK, K11, K22, NO1, N10, N20, N02, N11, N12, N21, N22, C14, C13, Q34;

REAL ARRAY R, I [1:4, 0:NWORDS], PSA, A, B [1:4, 0:NM1], C5N, C5W, CNW, C0, FREQ, OMEG4, PER, PS, Q5N, Q5W, QNW, SI[0:NM1], AVEPER, A0, A1, A2, B1, B2, BETA, CREST[0:1+ENTISEENMI/AVEFO11.
                                                                                                                                                                                                                                    005:0000:0
                                                                                                                                                                                                                                    005:0000:0
                                                                                                                                                                                                                                    005:0020:3
                                                                                                                                                                                                                                    005:0000:0
                                                                                                                                                                                                                                    005:0000:0
                                                                                                                                                                                                                                    005:0008:3
                                                                                                                                                                                                                                    005:0078:3
                             ENTIER(NP1/AVEFQ) ];
                                                                                                                                                                                                                                    005:0011:0
 HEAL ARRAY NAS, NAT, NAB, RLD, NAI, NA2, NA3, NA4, NA5, ANGI, ANG2, RNEW, NNN,
                                                                                                                                                                                                                                    005:0019:4
 XALPH[]: 1 + ENTIER(NMI/AVEFQ)], JACOB, KONE, KINO[O:NMI];
TIRECT FILE BUOYTAPE (KIND = 13, LABELTYPE = OMITTEDEOF, DENSITY = LOW,
PARITY = 0, MAXRECSIZE = NAORDS + 1);
                                                                                                                                                                                                                                    005:0019:4
                                                                                                                                                                                                                                    005:0029:4
                                                                                                                                                                                                                                   005:0729:4
                                                                                                                                                                                                                   DATA IS 0025 LONG
DATA IS 0003 LONG
 LIRECT ARRAY TAPEBUF[0:NWORDS];
LABEL ADDIR, AGAIN, EXIT, FINI, LOOPER, NEXT, PUN1, PUN2, PUN3, TAB2, TAB3;
                                                                                                                                                                                                                                    005:0740:4
                                                                                                                                                                                                                                    005:0030:4
                                                                                                                                                                                                                                    005:3730:4
PORMAT F5(" N ", K5, "PERIOD", X3, "A0=", X12, "A1=", X12, "A2=", X12, "B1=", X12, "B2=", XC, "DEG. IRUE", X5, "RMS DLGFEES", / );

FUR MAT F8(14, (2, F5.3, X1, 5(F12.4, X3), 2(F7.2, X7));

FORMAT F9(" ANG.", X4, "PERIOD", X3, "ACCEL.", X4, "SURFACE", X3, "N-SLOFE", X3, "E-SLOPE", X5, "IO-SN", X4, "QUAD-SN", X4, "CO-SE", X4, "QUAD-SE", X4, "CO-NE", X4, "CO-NE", X4, "QUAD-NE", X2, "ARVES BFAM");

FJRMAT F10(X113, "FROM", X5, "WDT4");

FORMAT F11(" FREQ.", X5, "SEC.", X3, "CM2/SEC4", X3, "CM*A2", X4, 2("PER HERTZ "), 4(" CM-/HZ. "), 2("PER HERTZ "), " DEG. (T)");

FGRMAT F12(E6.2.F8.2.10k10.2.2(X2.F6.1));
  005:0030:4
                                                                                                                                                                                                                                    005:0730:;
                                                                                                                                                                                                                                    005:00:0:4
                                                                                                                                                                                                                                    005:0130:4
                                                                                                                                                                                                                                    005:0630:4
                                                                                                                                                                                                                                    005:0030::
                                                                                                                                                                                                                                    005:0130:4
                                                                                                                                                                                                                                    105:03:0:4
                                                                                                                                                                                                                                    005:0030:4
FORMAT F12(E8.2, F8.2, 10E10.2, 2(X2, F6.1));
FORMAT F13(" AVERAGED DIRECTIONAL CUEFFICIENTS FOR .989 SEC. < T < ",
                                                                                                                                                                                                                                    005:0730:4
                                                                                                                                                                                                                                    005:0050:4
FORMAT F13(" AVENAGED DIRECTIONAL CUEFFICIENTS FOR .989 SEC. < I < ", F7.1," SEC.",/);

F0.1," SEC.",/
                                                                                                                                                                                                                                    005:0730:1
                                                                                                                                                                                                                                    005:0030:4
                                                                                                                                                                                                                                   005:0030:4
                                                                                                                                                                                                                                    005:0030:4
                                                                                                                                                                                                                                    005:00:01:4
                                                                                                                                                                                                                                    005:0330:4
                                                                                                                                                                                                                                    005:0030:4
                                                                                                                                                                                                                                   005:3730:4
                                                                                                                                                                                                                                   005:0030:4
FURBA! FINCELO.4, X5, 4(E4.2, X31);
                                                                                                                                                                                                                                   005:0030:4
                                                                                                                                                                                                                                   005:07:0:4
                                                                                                                                                                                                                                   005:0030:4
```

```
005:0030:4
PROCELURE TAPESTARY (DIRECTFILE, DB, KS, SF, SK, ERR);
                                                                                                    005:0330:4
                                                                                                    005:0030:4
VALUE RS, St, SR;
LIMECT FILE DIRECTFILE;
                           INTEGER RS, SF, SK;
                                                        BOOLEAN ERR:
                                                                                                    005:0030:4
                                           TIRECT ARRAY DB[0]:
                                                                                                    005:0130:4
065:0030:4
                                                                                                    005:07341:1
      THIS PROCEDURE IS FOR READING A FIELD DATE LOGGER TAPE BY MEANS
      OF DIRECT I/U. THE TAFE IS ADVANCED TO A SPECIFIED FILE GIVEN BY "SF" AND THEN TO A PECURD GIVEN BY "SR". THE EXPECTED NUMBER OF AGRDS EACH RECORD CONTAINS IS "RS". THE ACTUAL NUMBER OF AGRDS TRANSFERED FROM EACH RECORD AND THE READ ERROR TYPE ARE PRINTED
                                                                                                    005:0030:4
                                                                                                    005:0030:4
                                                                                                    005:0030:4
                                                                                                    005:0030:4
      JUT FOR EACH FILE AS WELL AS THE NUMBER OF RECORDS PER FILE. PRUCEDIRE TAPFSTART PEQUIRES FOREWARD DECLARATION OF DIRECT FILE
                                                                                                    005:0131::
                                                                                                    005:0031:4
                                                                                                    005:0030:4
      ALC DIRECT AKKAY DB.
                                                                                                    005:0337:.
                                                                                                     005:0630:4
105:0139::
BESIN
                                                                                                    105:0130:4
   INTEGER EDICT. NC:
                                                                                     TAPESTART IS SEGMENT 00107
                                                                                                    967:0999:0
FILE FRINT (KINE = PRINTER, MAXRECSIZE = 22);
                                                                                               DATA IS NOSA LONG
                                                                                               DATA IS ONO LONG
                                                                                                    067:0000:6
FOREST SKAC ("FILE", 13, " RICORI", 13, " CONTAINS", 15, " WORDS, ",
                                                                                                    007:0000:0
  "EKROK NO.", IZ);
WRITE(PRINT[SPACE 2], < "SPACE 10 FILE ", IZ, " RECURD ", IZ>, SF, Sk);
                                                                                                    907:0000:0
                                                                                                     007:0010:5
   EFR := FFLSE; & NO ERROR INDICATION.
                                                                                                    007:0011:4
      := 1;
                                                                                                     007:0012:2
   LUTCT := 1;
                                                                                                     007:0013:0
   HALLE EDICT LIS SF DO
                                                                                                     007:0013:5
   ELGIN
                                                                                                     007:0014:2
      READ (DIRECTFILE, RS, De[*]);
                                                                                                     007:0018:2
       wAIT(18[*]);
                                                                                                     007:0014:0
       IF UB[ 4]. LOEDF THEN
                                                                                                     007:0010:0
       BEGIN
                                                                                                     001:001C:3
         CLOSE(DIRECTFILE,*):

WRITE (FRINT[SPACE 2], <"EOF ENCOUNTERED FOR FILE ", 12, " OF",
13, " RECORD(S)">, EUFCT, RC);
                                                                                                     007:001E:0
                                                                                                     007:0020:3
                                                                                                     007:002E:5
          EOFCT := * + 1;
                                                                                                     007:0030:1
          DIRECTFILE. OPEN := TRUE;
                                                                                                     007:6031:5
          жC := 0;
                                                                                                     007:0032:3
       END ELSE
                                                                                                     007:0032:3
       BEGIN
                                                                                                     007:0933:7
          ₹3 := * + 1;
                                                                                                     007:0034:2
          WRITE(FRINT, SKRC, EOFCT, RC, DB[*].IOWORDS,DB[*].IOERKORTYPE);
                                                                                                     307:004b:1
      END
                                                                                                     007:0046:1
                                                                                     5
   Ehb:
                                                                                                     007:034B:4
                                                                                     4
   KC := 1;
                                                                                                     007:0040:2
   WHILE AC LSS SK DO
                                                                                                     007:0040:1
                                                                                                     907:0140:4
       READ (DIRECTFILE, RS, DB[*]);
                                                                                                     007:0051:4
       WAIT(DB[*]):
                                                                                                     077:0053:2
       ARITE(PRINT, SKRC, EDFCT, RC, DB[*]. IOHORDS, DB[*]. IOERRORTYPE);
                                                                                                     007:005A:1
       kC := * + I;
                                                                                                     007:0056:3
   END:
                                                                                                     007:0060:0
      TAPESTART;
                                                                                    TAPESTARTIONT) IS NOTE LONG
                                                                                                     005:0030:4
************************************
```

```
005:0037:4
FROCEDURE PRLATE (DA1);
                                                                                                        105:0(30:4
                                                                                                        nn5:0030:4
                                                                                                        005:0030:4
                                                                                                        005:0130:4
                                 INTEGER DAT:
VALUE DAT:
                                                                                                        005:0130:4
005:0030:4
                                                                                                        005:0130:4
      THIS PROCECUME DECODES THE DATE AND TIME INFORMATION CONTAINED IN THE LEATING 24 BITS OF FACH TAPE SECOND AND PRINTS THIS OUT.
                                                                                                        005:0030:4
                                                                                                        005:0030:4
                                                                                                        015:0030:4
                                                                                                        005:0030:4
  ************
                                                                                                        005:0130:4
                                                                                                        005:0030:4
   INTEGER ARRAY MONTHS[1:12];
                                                                                           PREATE IS SEGMENT 00009
   VALUE ARRAY MONTH: "JAN", "FEB", "MAR", "APR", "MAY", "JUN", "JUL",
                                                                                                        n19:0010:0
                                                                                                  DATA IS ONLL LONG
          "AUG", "SEP", "OCT", "NOV", "DEC");
                                                                                                        0.01:010:0
                                                                                                  DATA IS DONC LONG
                                                                                                        003:0010:0
   INTEGER YEAR, DAYS, HOUR, MINIO, MINI, NM;
                                                                                                        009:0000:0
   LAELL INI, EXIT:
   FILL MONTHS[*] WITH 31, 28, 31, 30, 31, 30, 31, 30, 31, 30, 31; COMMENT DAT (DATE AND TIME) IS IN THE FORM:

Y LD LUDD FULL BH HHHH MMM MMMM Y-YEAR, D-DAY, H-HOUR, M-M
                                                                                                        0:00:00:0
                                                                                                        009:0014:2
                                                  Y-YEAR, D-DAY, H-HOUR, M-MIN
                                                                                                        009:0004:2
                                                                                                        103:0014:2
            IN BINARY CODED DECIMAL DIGITS;
   YEAR := IF DAT.[23:1] EQL 1 THEN 73 ELSE 72;

DAYS := DAT.[22:2] * 100 + DAT.[20:4] * 10 + DAT.[16:4];

HOUR := DAT.[12:2] * 10 + DAT.[10:4];
                                                                                                        009:0004:2
                                                                                                        009:0017:5
                                                                                                        009:0000:2
                                                                                                        009:0001:2
   NIN1" := LAT.[6:3];
                                                                                                        0.19:0011:5
   1141 := DAT. [3:4];
   IF YEAR MOD 4 EQL () THEN MONTHS[2] := 25;
FOR NM := 1 STEP 1 UNTIL 12 DO
                                                                                                        nn9: rn12:2
                                                                                                        009:0015:1
       IF DAYS LED MONTHS NM | THEN GO FND ELSE DAYS := FAYS-MONTHS (NM); #RIFE(PRINTEF, < "ERROR IN PROMIE: DAYS TOO LARGE">);
                                                                                                        009:0015:5
                                                                                                        nn9:0010:2
                                                                                                        009:0021:5
    GO EXIL:
  FYD: WRITE(PRIMIER, <"DATE: ", 12, X1, M3, X1, 12, "; FIME: ", 12, ":", 11,11>, DAYS, MONTH[NM-1], YEAR, HOUR, MIN10, MIN1);
                                                                                                        009:0022:2
                                                                                                        009:0024:1
                                                                                                        009:0038:1
       ARITE(PRINTER, </>);
                                                                                                        005:0640:4
  EXIT: FND FRDATE;
                                                                                          PRDATE(009) IS 0045 LONG
                                                                                                        005:0030:4
```

.

```
005:0630:4
                                                                                                 005:0030:4
PROJEDURE READTAPE(NFILE, REC. CHANNELS);
                                                                                                 005:0030:4
                                                                                                 005:0030:4
                                                                                                 005:0030:4
VALUE NEILE, REC. CHANNELS;
                                                                                                 005:0330:1
INTEGER NFILE, REZ. CHANNELS;
                                                                                                 nn5:0030:4
                                                                                                 005:0030:4
005:0330:4
                                                                                                 005:0630:4
      THIS PROCECURE READS ONE RECORD/CALL BY MEANS OF DIRECT I/O.
                                                                                                 005:0030:4
      THE HIGH ORDER 24 BITS OF THE FIRST WORL, WHICH CONTAIN THE DATE
                                                                                                 005:0339:4
      AND TIME INFORMATION, ARE ISOLATED INTO THE VARIABLE "DATE".
                                                                                                 005:0030:4
      THE FOUR CHANNELS OF DATA ARE SEPARATEL AND CONVERTED INTO THEIR
      APPROPRIATE UNITS. THE MEAN VALUE OF EACH TIME-SERIES IS FOUND
                                                                                                 005:0030:4
                                                                                                  005:0130:4
      AND SUBTRACTED OFF. VARIOUS ERROR DIAGNOSTICS ARE PRINTED OUT.
                                                                                                  065:0630:4
      READTAPE REQUIRES FOREWARD DECLARATION OF TAPEFILE & DIRECT ARRAY.
                                                                                                  005:0630:4
                                                                                                  005:0331:1
005:0030:4
BEGIN
                                                                                                 005:0330:4
    INTEGER DATE, ERRCT, IOERR, J. L. LIMIT;
                                                                                   READTAPE IS SEGMENT 00000
                                                                                                  000:0000:0
    HEAL CF. XMEAN:
                                                                                                  nnc:0000:1
    BOOLEAN ARRAY SACH[1:4];
                                                                                                  0.00:0000:0
    LABEL CONT, FREUR, LEAVE;
OFFINE SETFIELD(SUBC, LBF) = OU R(L,J) := TAPEBUF(SUBC). [LBF:12]
UNTIL J := * + 1 GEQ NWORDS*;
                                                                                                  nnc:nnan:a
                                                                                                  0.00:000:0
                                                                                                  00c:0010:0
                                                                                                  0.60:0000:0
                                                                                                  nnc:0390:4
   COMMENT READ THE NEXT RECORD USING DIRECT 1/0;
                                                                                                  nnc:0000:4
    kead(Buoytape, Nwords+1, TapeBuf(*));
#AIT( TapeBuf(*));
                                                                                                  nac:0014:5
                                                                                                  nnc:nnn6:3
     IOERR: = TAPEBUF[*]. IOERRORTYPE;
                                                                                                  nnc:0009:1
    WRITE(FRINTER[SPACE 2]);
#RITE(PRINTER, < "FILE NO.", I3, " RECORD", I3, " CONTAINS", I5,
### 40RDS ERROR NO.", I2>, NFILE, REC, TAPEBUF[*]. IO#ORDS, IOERR);
                                                                                                  OUC: UUJE: 3
                                                                                                  00C:0010:2
                                                                                                  nnc: n024:1
       CASE IGEAR OF BEGIN
                                                                                                  nnc:nn26:3
        & O NO ERKUR:
                                                                                                  nnc:nn26:3
       BEGIN ARITE(PRINTER, < "NOT READY">); GO TO ERROR
                                                               : END:
nnc: no 2D: N
                                                                                                  000:0031:3
                                                                                                  nnc:0036:2
                                                                                                  000:0030:5
                                                                                   5
                                                                                                  000:0043:2
                                                                                                  00C:004b:0
                                                                                                  000:0052:4
       BEGIN WRITE(PRINTER, <"ERROR N7">); GO EXIT; END;
BEGIN WRITE(PRINTER, <"ERROR N 8">); GO EXROR; END;
BEGIN WRITE(PRINTER, <"SHORT RECORD ", FIO. 3, " CHARACTERS">,
                                                                                                  nnc:nn5A:2
                                                                                                  000:0050:5
                                                                                                  nnc: nn63:3
               TAPEBUF[*]. IOCHARACTERS);
                                             GO TO ERROR:
                                                                                                  00C:0071:1
    END:
                                                                                                  nnc: nu76:3
    1 := 1;
                                                                                                  000:0077:1
    DO SWIH(L) := BOOLEAN(CHANNELS. [4-L:1]) UNTIL L := * + 1 GTR 4; COMMENT DIMP HEADER INFORMATION ON THE LINE PRINTER;
                                                                                                  000:0070:3
                                                                                                   000:6070:3
     CONT:
                                                                                                   000:0070:3
    DATE := 0 6 TAPEBUF[0] [23:47:24];
                                                                                                   OOC: 067E:3
    PACATE(DATE):
                                                                                                   OOC: 077F: 4
       FOR L : * I STEP 1 UNTIL 4 DO
                                                                                                   000:0080:2
       IF SWCH[L] THEN BEGIN
```

```
nnc:0081:5
   J := f:
CASE L-1 OF BEGIN
                                                                                                                     onc:0085:3
     CETFIELL(J.23):
                                                                                                                     Onc:0036:2
      GETFIELD(J.11);
                                                                                                                     noc:0091:1
      GE1FIELL(J+1, 47);
                                                                                                                     nac:0037:2
      GETFIELD(J+1, J5):
                                                                                                                     nnc: Gnst: 3
   END OF CASES:
                                                                                                                     nnc:nn3F:3
      REPLACE POINTER(I[L.O]) BY 4"ONHO 3000000" FOR NWORDS WORDS:
                                                                                                                     Onc:nna2:0
      FRECT := 0;
MEAN(L) := x[L,0];
                                                                                                                      nnc:nna2:4
                                                                                                                      000:0045:1
     IF L EUL 2 THEN LIMIT:=256 ELSE LIMIT:=1024;
                                                                                                                     nnc:nna9:n
                   LIMIT=256 CORRESPONDS TO 22.5 DEG. AZIMUTH
                                                                                                                      anc:0049:0
                   LIMIT = 1024 CORRESPONDS TO 22 DEG. TILT OR .5*G ACCEL.
                                                                                                                      nnc:00A9:0
     J := 1;
                                                                                                                      000:0149:1
      COMMENT ERROR IN LATA FIRST OCTAL DIGIT DIFFERENCE;

IF ABS(R[L,J] - R[L,J-1]) GTR LIMIT THEN

IF ERRCT := *+1 GTR 4 THEN BEGIN

***KITE(PRINTER, <"ERRCK IN READTAPE: TOO MANY BAD DATA PCINTS.",

" LAST ONE AT ", 14, ".">, J);
     DG BEGLY
                                                                                                                      OOC: 01A9:4
                                                                                                                      nnc:3149:4
                                                                                                                      OOC: GOAD: 4
                                                                                                                      nnc:0080:3
                                                                                                                      nnc:0062:2
                                                                                                                      nnc:n13E:4
      GU ERROA:
                                                                                                                      nnc: rnbF:1
     END LLSE BEGIN
         ARITE(PRINTER, <"ERROR IN READTAPE: BAD DATA POINT AT: RUM (", 11, "), COLUMN(", 14, "). IN REFRENCE TO ", F7.2, ", POINT F7.2, " OUT OF LINE">, L,J,R[L,J-1], R[L,J]);
                                                                                                                      10C:078F:4
                                                                                                                      nnc:nncl:3
                                                                                                                      060:0001:3
060:0006:4
000:000A:1
           k[L,J] := k[L, J-1];
                                                                                                                      ONC: NODA:1
                                                                                                    6
            MEAN(L) := MEAN(L) + K(L,J);
                                                                                                                      005:000E:0
        END JALIT 1 := * + 1 GEQ NWORDS;
                                                                                                                      nnc:nnen:2
       XMEAN := MEAN[L] / NWORDS:
CF := CAL[L]:
                                                                                                                      nnc: n0 = 2: 2
                                                                                                                      ONC: 60 £3:5
       MEAN[L] := (XMEAN - 2648) * CF;
      HEAN(L) = (ALLEN

IF L EQL I THE V

WRITE(FRINTER, < "MEAN VALUE OF CHANNEL ", II, " IS ", Fll. 5,

" CN./SEC.**2">, L, MEAN(L) ELSE

WRITE(PRINTER, < "MEAN VALUE OF CHANNEL ", II, " IS ", Fll. 5,

" RADIANS.">, L, MEAN(L));
                                                                                                                      nnc:nnE6:1
                                                                                                                      OOC: 00E7: 4
                                                                                                                      DUC: 00E9:4
                                                                                                                      nnc:07F8:4
                                                                                                                       nnc:nGFB:n
                                                                                                                       nnc:nlna:1
       IF I. EQL 4 THEN ARITE(PRINTER, </>);
                                                                                                                       nnc:0111:0
         1 := 0;
       DU R[L.J] := (R[L.J]-XMEAN) * CF UNTIL J:= * + 1 GEQ NAORDS;
                                                                                                                       onc:0111:4
                                                                                                                       nnc: 0116:1
      FND:
                                                                                                                       nac:nlla:3
   30 LERVE:
                                                                                                                       000:0118:0
  ERFUR: ERK := THUE;
                                                                                                                       ONC:0118:4
LEAVE: END READTAPE:
                                                                                                    READTAPE( OC) IS 012E LONG
                                                                                                                       005:0730:4
```

```
005:0131:4
005:0030:4
PROCEDURE ALJPHASE (R.I.SI, CO. MEX, CHANNELS, NYC, SAHIN);
                                                                                                        105:11:1:4
                                                                                                        005:0030:4
FEA - ARRAY R. [[1,0], SI, CG[0]:
                                                                                                       005:0137:4
INTECER MEX. CHANNELS;
                                    REAL NYU;
                                                              BUOLEAN SAHIN:
                                                                                                        005:0130:4
3
                                                                                                        005:0030:4
005:0130:4
                                                                                                        nn5:n13n::
     FOR EACH CHANNEL, J. THIS PROCEDURE CORRECTS THE TIME-SERIES BY
                                                                                                        005:00:0:4
     TULTIPLYING ITS FOURIER TRANSFORM BY THE APPROPRIATE INVERSE FREQ.
                                                                                                       005:0130:4
    RESPONSE OF ITS CUTPUT FILTER AND THEN APPLYING THE REVERSE TRANSFORM TO THE PRODUCT. THE RESULTING REAL TIME-SERIES IS THEN
                                                                                                       005:0030:4
                                                                                                       005:0131::
     SCALED AND RETURNED THROUGH ARRAY 'R.
                                                                                                        005:0030:4
    THE CHANNEL #1 TIME HISTORY IS CONVERTED TO SURFACE ELEVATION.
                                                                                                        005:0030:4
     AMEN THE SAMPLE & HOLD MODULES ARE OPERATING, SET SAMIN-TRUE.
                                                                                                       005:0130:4
    NOTE: PROCEDURE SINCOS MUST BE CALLED PRIOR TO CALLING ADJPHASE.
                                                                                                       005:6630:4
    ADJPHASE REQUIRES FOREWARD LECLARATION OF ARKAYS.
                                                                                                       nn5: 1:030:4
                                                                                                       nn5:0630:4
aa5:0131:4
EECIN
                                                                                                       005:1130:4
INTEGER HEPTS, J, K, N, NPTS:
                                                                                                       005:0130:4
                                                                                        ADJPHASE IS SECMENT COCCO
HEAL A.B.CS. CDS.DS.F1.F2.F1.SCALE, SDS.SV.SQ2.TAU, TEMPI. TEMPR. VARIA,
                                                                                                        010:0010:1
     W.WII.w12, WO.WG2, 20, ZS;
                                                                                                       nct: com: n
                                                                                                       ו:חונה:פרף
hFTS:=0 & 1[SEX:0:1];
                               & = ZAAMEX
                                                                                                        n:p:nnnn:n
3C4LE: =2./ APT3 * *2;
F1:=3.1415926535b; HFPTS:=NFTS DIV 2; SU2:=SQRT(2.); W:=2.*PI*NYU/HFPTS; FAJ:=7.01; &(SECONDS) SCAN INTERVAL BETWEEN CHANNEL SAMPLES.
F1:=1.0; &(HERTZ) CUT-CFF FREQ. OF CHANNEL #1 FILTER.
F2:=20.0: &(HERTZ) CUT-GFF FREQ. FGR CHANNELS 2,3,4 FILTERS.
                                                                                                       100:2021:3
                                                                                                       000:0003:5
                                                                                                       ו:סוחח:טהח
                                                                                                       UST: UDUL: 3
                                                                                                       nnp:0011:0
*Il:=1./(2.*FI*F1);
                                WI2:=1./(2.*PI*F2);
                                                                                                       000:0012:3
                                                                                                       nab:nila:4
+0k J:=) STEP 1 UNTIL 4 TO IF CHANNELS.[4-J:1] NEO O THEN BEGIN EFF(R[J,*],I[J,*],SI,CO,MEX): BITRV2(R[J,*],I[J,*],MEX):
                                                                                                       OCD: GPlA:4
                                                                                                       000:0010:5
VALL: = 0 . :
                                                                                                       NGU: NO26:3
N:=); DO VARN:=^+(R[J, \%]^*A^2 + I[J, \%]^*/2)^*SCALE UNTIL N:=<math>^++1 GEQ HFPTS. IF J EQL 1 THEN
                                                                                                       115:nn27:1
                                                                                                       000:062F:1
ARTIECPRINTER, <"VARIANCE OF INPUT TIME HISTORY CHAN. #", II." 13 ", E12.5,
                                                                                                       003:0327:5
          " CM. **2/SEC. ** 4">, J, VARN)
                                                        ELSE
                                                                                                       000:6632:1
WALLE ( PALNER, < "VARIANCE OF INPUT TIME HISTORY CHAN. "", II, " IS ", E12.5,
                                                                                                       กาม:กาเก:1
          " KADIANS**2">, J, VAKN);
                                                                                                       001:0042:3
                                                                                                       000:0050:4
D3:=(J-1)*TAJ*#;
                           SDS: = SIN(DS);
                                                 CDS:=COS(DS);
                                                                                                       1:00:01:01:1
}:=D;
                                                                                                       nn1:nn55:5
IAKS NPTS DO BEGIN
                                                                                                       000:0006:3
          IF N ILC HEPTS THEN K: =- N ELSE K: = NPTS - N;
                                                                                       5
                                                                                                       000:0054:4
                                           1 WHERE S=(I-1) TAU*W*K; K=1,2..
                                                                                                       000:005F:1
         IF N NEQ 0 AND J NEQ 1 THEN BEGIN ZC:=CS;

IF N EQL HFPTS+1 THEN ZS:=-SN;

CS:=ZC*20S+ZS*S0S; SN:=ZS*
                                                           25:=5N;
                                                                                                       nnp:nnsF:1
                                                                                                       nnu:nn62:5
                                                 S4: =25*CDS-ZC*SDS;
                                                                                                       nno:nno5:3
          ENL ELSE BEGIN
                                                                                                       nnt:[G6A:1
                      CS:=1.;
                                   SN:=0.;
                                               END:
                      CS:=1.;
SN=SIN(S)=SIN(S+DS), CS=COS(S)
E1: TEMPI:=I[J,N];
                                                                                                       BAD: OF 64:4
                                                  CS = COS(S) = COS(S+DS).
                                                                                                       indeco:don
          TEMPR: = R[J, N];
                                                                                                       070:00:5:1
```

```
005:0070:5
005:0070:5
A FUNCTIONS A AND B ARE REAL AND IMAGINARY PARTS OF INVERSE FILTER RESP. IF J ELL 1 THEN BEGIN
                                                                                                                                                                                                                                                                              06p: 6072:0
                                                                                                                                                                                                                                    6
                                                         W02:=(W0:=W*K*#11)**2 - 1.:
                                                                                                                                                                                                                                                                              nnp:n170:1
                                                         IF SAHIN THEN BESIN A:=ADZ: H:=SJZ*NO: END
                                                                                                                                                                                                                                                                              000:079:4
                                                         ELSE BEGIN
                                                         ELSE BROOMS RESERVED TO BE SEEN OF STREET OF S
                                                                                                                                                                                                                                                                              200:00/4:1
                                                                                                                                                                                                                                                                              nob: 6070:0
                                                                                                                                                   END:
                                                                                                                                                                                                                                                                              000:007F:5
                                                                                                                                                                                                                                    7
                                                                                                                                                                                                                                                                              000:0131:5
                                                                                                                                                                                                                                                                              nnp: nn 35:3
                                                                                                                                                                                                                                                                               000:0069:1
                            ENL ELSE BEGIN
                                                                                                                                                                                                                                                                              005:0139:4
                                                          40:= 4 K A 412:
                                                                                                                                                                                                                                     6
                                                         IF SAHIN THEN BELIN A:=1.; B:=w0;
A:=CS + w0*SN; B:=d0*CS - SN;
IF N EQL HFPTS THEN B:=0.;
k[J,N]:=A*TEMPR - E*TEMPI;
I[J,N]:=A*IEMPI + d*ILMPR;
                                                                                                                                                                                                                                                                              001:0088:3
                                                                                                                                                                           END ELSE BEGIN
                                                                                                                                                                                                                                                                               200:0033:3
                                                                                                                                                                                                                                                                               000:0095:3
                                                                                                                                                                                                                                                                               000:0099:1
                                                                                                                                                                                                                                                                               nap: 0090:5
                           LND:
                                                          h:=*+1;
                                                                                                                                                                                                                                                                               nno:nnaE:1
END:
                                                                                                                                                                                                                                                                               ner:cosF:2
                                                                                                                                                                                                                                                                               1:4t00:c06
                                           & CONVERT ACCELERATION TRANSFORM TO SURFACE ELEVATION.
 v:=1:
                                                                                                                                                                                                                                                                               0.01:0090:0
 IF J ELL I THEN BEGIN
                                                                                                                                                                                                                                                                               01:140:dr
                                                                                                                                                                                                                                      5
                             THEY (NPTS-1) DO SECIN
                                           IF N LEG HEPTS THEN
#0:=-1./(N*W)**2 ELSE #0:=-1./((NPTS-N)*#)**2;
                                                                                                                                                                                                                                                                               00D:0645:4
                                                                                                                                                                                                                                                                               nan:nage:3
                                                                                                                                                                                                                                                                                0.01E:0
                                           R[1,N]:=#0*R[1,N];
                                                                                                                                     1[1, N]: ##0*1[1, N];
                                                                                                                                                                                                                                                                               กกอ:กางง:2
                                           N:= 4+1;
                                                                                                                                                                                                                                                                               060:0624:4
                           ENL:
                                                                                                                                                                                                                                                                                105:10:5:5
 FAD FTRF YECIN
                                                                                                                                                                                                                                                                                060:0016:4
                                                                                                                                                                                                                                                                                000:0750:2
                                                                                                                       FFTR(R(J,*), I[J,*], SI, CO, MEX):
  BEIRV2(R[J,*], [[J,*], MEX);
                                                                                                                                                                                                                                                                                กาว:การระก
                                                                                                                                                                                                                                                                                0.1400:000
 Limn; DO F[J,K]:=R[J,K]/NPTS UNTIL N:=A+1 SEU NPTS; PEPLACE POINTER(I[J,A]) BY N. FOR NPTS WORDS;
                                                                                                                                                                                                                                                                                nnp:0105:4
                                                                                                                                                                                                                                                                                 n60:00c8:1
  IND:
                                                                                                                                                                                                                                                                                000:0008:1
  . 4D;
                                                                                                                                                                                                                                       ADJPHASE(NOD) IS NOD4 LOSS
3 005:0030:4
  INE FEJFHASE;
```

```
005:0130:4
005:00:00:4
   LAST:= 4"C5";
                                                                                                                              005:0031:3
    46ST: - 4"E5";
   TAPEBUF[*].IUCW := # 6 1[44:1] 6 6[33:3] 6 1[30:1]; 6 7-TRK, 200 BPI
TAPEBUF[*].IUCM := # 6 1[7:1]; 8 SUPPRESS PARITY ENROR RETRY.
FSIEF := XNYQJISI * 2./NWORDS;
UMEG := 1./(2. * FI * FSTEP);
                                                                                                                              005:0032:2
                                                                                                                              005:0035:1
                                                                                                                              005:0037:0
                                                                                                                              065:003A:1
    SINCOS(SI, CO, MEK); & SET UP SIN-COS TABLE FOR FFTF
                                                                                                                              005:003F:1
                                                                                                                              005:0041:1
    J := 1:
                                                                                                                              005:0041:5
    LC PEGIN
        FREG[J] := FSTEP * J;
                                                                                                                              075:0041:5
       PER[J] := 1./rREU[J];
OME.4[J] := (OMEG/J) ** 4;
                                                                                                                              005:0(43:4
                                                                                                                              005:0046:3
   KIMO[J]:=(K)NE[J]:=.U402840996*(FSTZP*J)**2;

JACOB[J]:=480200./(2.*PI*FSTEP*J)**3;

END UNTIL J:= * + 1 GEQ N;

PS[f]:= OMEG4[0]:= FREQ[0]:= PER[0]:= 0.;
                                                                                                                              005:00:9:0
                                                                                                                              005:004E:0
                                                                                                                              075:3754:3
                                                                                                          3
                                                                                                                              005:0056:2
    14 := 0:
                                                                                                                              005:0059:5
                                                                                                                              005:005A:3
    FEAD(CARD, <2(15, X5), F6.1, X1, A1, X5, F6.1>, IAV, SAHIN, MAGDEV, EORW, TLIM);
    READICARD, <6(L5, 45)>, TABLE1, TABLE2, TABLE3, PUNCHXS, PUNCH2S, PUNCHDS);
II TLIM LEQ 0. THEN TLIM:=NM1/ANYQUIST;
                                                                                                                              015:0070:5
                                                                                                                              00:5:0089:2
    IF LAV THEN ARTTELPRINTER, < "SPECTRAL BANDS AVERAGED ON LOGRITHMIC ",
                                                                                                                              015:0038:5
                                                                                                                              005:008E:3
                                        "BAS IS . ">)
                                                                    ELSE BEGIN
   FREEDOM: =2*NREC*AVEFU:
WRITE(PRINTER, <12, " ADJACENT FREQS. AVERAGED YIELDING ",13,
" DEGREES OF FREEDOM IN SPECTRAL ESTIMATES.">,
FND:
                                                                                                                              035:0332:4
                                                                                                                              005:0134:4
                                                                                                                              005:0056:3
   AVEFG, FRELDOM); END;
IF MEX LEJ 3 AND LAV THEN BESTN
WRITE (FRINTER, <"TIME HISTORY TOO SHORT TO IMPLIMENT LOGRITHMIC"
," AVERAGINS.">); GO TO FINE; END;
                                                                                                                              005:0057:2
                                                                                                                              005:0044:4
                                                                                                                              005:00A6:3
   " AVERAGIN;. ">); GO IO FINI; END;

"KRITS(PRINTER, < "SAMPLE & HOLD MODULES IN=", L5>, SAHIN);

"KRITS(PRINTER, < "MAGNETIC COMPASS CEVIATION=", F6.1, X1, A1, ".", //>,
                                                                                                                              035:0048:2
                                                                                                                              nn5:nn4C:3
                                                                                                                               005:00EA:4
                                                                                                                               005:00BD:2
                          PAGDEV, EORW);
                                                                                                                              005:013A:1
    HASDEV: = MASDEV PI/180 .;
                                                                                                                              nos: coct: 4
WRITE(PHINTER, <6(L5, X5)>, TABLE1, TABLE2, TABLE3, PUNCHXS, PUNCHPS, PUNCHDS);
                                                                                                                              005:01£7:4
                                                                                                                               065:0CE7:4
    TAPESTART ( SUCYTAPL, TAPEBUF, NAURDS+1, NFILE, FIRSTREC, ERR):
3
                                                                                                                               005:00EB:4
                                                                                                                              nns:nlEB:i
REC:=1:
NEXT: BEGIN READTAPE(NFILE, REC+FIRSTREC-1, CHANNELS);
                                                                                                                               005:00FC:5
        IF NOT ERR THEN ADJPHASE(R,1,SI,CO,MEX,CHANNELS,XNYQJIST,SAHIN)
ELSE GO TO AGAIN;
                                                                                                                               005:00EF:2
                                                                                                                               005:0014:1
                                                                                                                               005:0014:5
        NN:= NN + 1;
                                                                                                                               005:00%6:1
4
                                                                                                                               005:0076:1
       IF EORW EUL EAST THEN DO R[2,<]: ** + MEAN[2] + MAGDEV UNTIL K: **+1 GEO NWORDS ELSE IF EORW EUL WEST THEN DO R[2,<]: ** + MEAN[2] - MAGDEV
                                                                                                                               005:00F6:5
                                                                                                                               005: COFA: 2
                                                                                                                               005:0070:2
                                                                                                                               005:0101:2
                                            UNTIL K:= +1 GEQ NWORES ELSE GO TO FXIT;
                                                                                                                               005:0174:2
        K:=0:
                                                                                                                               005:0165:0
        CONVERT ANGLE TIME HISTORIES TO SLOPE TIME HISTORIES CHANS. 3,4.
                                                                                                                               005:0175:0
        THRU AMONDS DO RECLA
                                                                                                                               005:0109:1
               SINAZ:=SIN(R[2,K]);
                                                      COSAZ:=COS(R[2,K]);
                                                                                                                               nn5:n1nu:1
                TANROLL: = TAN(R[3,K]);
                                                     TANPITCH:=TAN(R[4,K]);
               COSPITCH:=COS(R[4,K]);
R[3,K]:= · COSAZ*TANROLL/COSPITCH - SINAZ*TANPITCH;
                                                                                                                               005:0111:3
                                                                                                                               075:0113:4
                                                                                                                               005:6117:4
               <[4, K]:= +SINAZ*TANROLL/CUSPITCH - COSAZ*TANPITCH;
```



```
IF EOR# EQL EAST THEN R[2,K]:=* - MEAN[2] - MAGDEV ELSE R[2,K]:=* - MEAN[2] + MAGDEV;
                                                                                                               005:0110:3
                                                                                                                005:011):4
                                                                                                                005:0123:0
                                                                                                                005:0124:2
       END:
                                                                                                                005:0125:3
                                                                                                                005:0125:3
3
                                                                                                                005:0125:3
       FOR NCHANNEL:=1 STEP 1 UNTIL 4 DO IF CHANNELS.[4-ACHANNEL:1] NEQ 0
                                                                                                                005:0127:5
       THEN BEGIN IF NCHANNEL GEG 2 THEN BEGIN
                                                                                                                005:012A:0
            FFT(F[NCHANNEL,*], I[NCHANNEL,*], SI, CO, MEX);
BITRY2(F[NCHANNEL, *], I[NCHANNEL, *], MEX);
                                                                                                                005:012E:2
                                                                                                                005:6131:4
                                                                                                                005:0131:4
                                                                                                                005:6131:4
       CALCULATE FOWER SPECTRA: CALCULATE VARIANCES.
1
                                                                                                                005:0131:4
                                    K:=0;
       VARN: = 0.;
                                                                                                                005:0133:0
           DO BECIN
              X := (R[NCHANNEL, K] ** 2 + I[NCHANNEL, K] ** 2)*SCALE;
IF NCHANNEL EQL 1 AND K LSS INTEGER(1./(TLIM*FSTEF)) THEN
                                                                                                                N65:0133:0
                                                                                                                005:0137:3
                                                                                                                005:0138:0
              X:=0.;
                                                                                                                005:0130:1
               A[NCHANNEL,K]:=R[NCHANNEL,K]: B[NCHANNFL,K]:=I[NCHANNEL,K];
                                                                                                                005:0142:3
               VRRN := * + X;
                                                                                                                005:0143:5
              POA(NCHANNEL, K) := IF NN EQL 1 THEN X ELSE
PSA(NCHANNEL, K) + X; END UNTIL K:=*+1 GEQ N;
                                                                                                                905:0147:3
                                                                                                                nn5:014B:5
                                                                                              5
                                                                                                                005:0143:5
    TASE NCHANNEL-1 OF BEGIN
   WHITE(PRINTER,
"HEADING VARIANCE=",E12.5," CM**2">,VARN);
WHITE(PRINTER,
"HEADING VARIANCE=",E12.5," RADIANS**2">,VARN);
WHITE(PRINTER,
"N-S SLOPE VARIANCE=",E12.5," SLOPE**2 (NO UNITS)">,
                                                                                                                005:014E:3
                                                                                                                005:0150:1
                                                                                                                005:016B:4
                                                                                                                005:0160:3
           CASA):
                                                                                                                005:0174:1
    WEITE(PRINTER, < "E-W SLOPE VARIANCE=", E12.5," SLOPE**2 (NO UNITS)",
                                                                                                                005:0170:0
           ////>, VAKN);
                                                                                                                nn5:6186:4
    END OF CASES:
                                                                                                                nn5:0136:0
*
                                                                                                                005:018B:0
                 * FND OF FFT LCOP. ......
       ENL:
                                                                                                                005:0130:2
                                                                                                                 nn5:0161:2
       CALCULATE CROSS SPECTRA
*
                DO CSN[K]:=*+(A[1,K]*A[3,K] + b[3,K]*B[1,K])*SCALE
                                                                                                                nn5:0181:2
       K:=1;
                                                                                                                005:0153:2
                UNTIL K:= *+1 GFU N - 1;
                                                                                                                003:0116:5
                DO QSH[K]:=*+(A[3,K]*B[1,K] - A[1,K]*B[3,K])*SCALE
                                                                                                                005:0150:5
                UNTIL F:=*+1 GEQ N - 1;
                                                                                                                005:0140:2
                DO CSA[<]:=*+(A[1,K]*A[4,K] + B[4,K]*B[1,K])*SCALE
       K:=1:
                                                                                                                 005:01A6:2
                UNTIL K:= *+1 GEQ N - 1;
                                                                                                                 005:0143:5
                DO QSA[K]:=*+(A[4,K]*B[1,K] - H[1,K]*B[4,K])*3CALE
       K:=1;
                                                                                                                 005:01AF:5
                UNTIL K:=*+1 GEQ N - 1;
                                                                                                                005:0183:2
                UO CHA[K]:=*+(A[3,K]*A[4,K] + B[4,K]*B[3,K])*SCALE
       K:=1:
              JNIIL K:= *+1 GEU N - 1;

LO \NW[K]:= *+(K[4,K]^B[3,K] - A[3,K]*B[4,K])*SCALE

UNTIL K:= *+1 GEU N - 1;

DO PS[K]:= *+(A[1,K]**2 + B[1,K]**2)*SCALE/OMEG4[K]
                                                                                                                 005:0139:4
                                                                                                                 nn5:01BD:1
       K:=1;
                                                                                                                 005:0103:3
                                                                                                                 nn5:n1:7:0
       K:=1:
                UNTIL A := *+1 GEU N - 1;
                                                                                                                 005:0100:1
                                                                                                                 005:010F:4
ł
                                                                                                                 005:01CF:4
       ENL:
                                                                                               3
                                                                                                                 005:012F:4
                                                                                                                 005:01CF:4
AUAIN: REC: = *+1;
                                                                                                                 005:0101:7
IF REC LED MREC THEN CO TO NEXT:
                                                                                                                 005:0112:2
                                                                                                                 005:0102:2
EKIT: IF NN STR 7 THEN BEGIN
                                                                                                                 nn5:0113:3
        NCHANNEL:=1;
                                    2:=1./NN;
```

```
105:0107:1
005:0117:0
      D) SECIN
                                                                                                                             005:0107:4
           K:=1:
           IF BOOLEAN(CHANNELS. [4-N2HANNEL:1]) THEN
IF NCHANNEL EQL 1 THEN DO BEGIN
                                                                                                                             005:0119:2
                                                                                                                             005:0108:0
                                                  PS[K]: * * 2:
                                                                                                                             005:0110:5
                                                  PSA[1,K]: * * Z;
                                                                                                                             nn5:nlrF:n
                                                  UNTIL K: **+1 GEQ N-1 ELSE
                                                  DO PSA[NCHANNEL,K]: ** *
                                                                                                                             005:01E1:4
                                                                                                                             005:0164:1
                                                  UNTIL R:=*+1 GEQ N-1 ELSE
                                                                                                                             005:0127:3
       ENT UNTIL NCHANNEL: = *+1 GTR 4;
                                                                                                                             nn5:01E9:>
       END ELSE BEGIN ARITE(PRINTER, < "UNSUCCESSFUL TAPE READ" > );
                                                                                                                    DATA IS NOTC LONG
                                                                                                                             ans: 01 EF: 4
                                                     END:
                            GO TO FINI:
                                                                                                                             005:01:0:1
                                                                                                                              005:01:0:1
                                                                                                                              005:0160:5
       K:= 0;
       005:0112:0
                                       QSN[K]:=* * Z;
CN#[K]: ** * Z;
                                                                  CSW[K]: ** * Z;
                                                             CSW[K]:=* * 4;
UNW[K]:=* * 2;
                                                                                                                              nn5: n1 F7: 3
                                                                                                                              005:01FL:0
                                                                                                                              005:01FF:2
        WRITE(PRINTER[SKIP 1]);
                                                                                                                              005:0274:3
       FOR NIHANNEL:=1.3.4 DO BEJIN
                                                                                                                              005:0206:2
                                       K : = (1:
            VARN:=0.;
                                                                                                                              015:027C:4
           PO VARN: #A + PSA[NCHANNEL,K] UNTIL K: #A+1 GEQ N;

IF NCHANNEL EQL 1 THEN

#RITE(PRINTER, < "AVERAGE VARIANCE OF ", IZ," RECORDS, CHAN. "",

#RITE(PRINTER, < "AVERAGE VARIANCE OF ", IZ," RECORDS, CHAN. "",

#RITE(PRINTER, < "AVERAGE VARIANCE OF ", IZ," RECORDS, CHAN. "",
                                                                                                                              005:0211:2
                                                                                                                              005:0212:0
                                                                                                                              005:0214:2
                                                                                                                              005:0211:0
                                                                                                                              005:0224:4
            #RITE(PRINTER, < "AVERAGE VARIANCE OF ", 12," RECOPDS, CHAN. N", 11," * ", E12.5," SLOPE**2 (NO UNITS)", />, HREC, NCHANNEL, VARN);
                                                                                                                              005:0227:0
                                                                                                                              005:0237:1
                                                                                                                              005:023A:3
            ENL:
                                                                                                                              005:023A:3
nn5:n238:2
                                                                                                                              005:0230:1
                                                                                                                               nn5:0249:I
                                                                                                                               005:0248:0
                                                                                                                               nn5:324E:4
                                                                                                                               nn5: n257:3
                                                                                                                               005:0262:2
                                                                                                                               005:020E:1
ARITE(PRINTER, <14,3E10.2, X18,5E10.2>, J, FREQ[J], PER[J], OMEG4[J],
IF CHANNELS.[3:1] EQL 1 THEN PS[J], FOR NCHANNEL: #1,2,3,4 DO
IF CHANNELS.[4-NCHANNEL:1] EQL 1 THEN PSA[NCHANNEL,J])
UNTIL J: #4+1 GEQ N;
                                                                                                                               015:020E:5
        J := 0:
                                                                                                                               005:0230:2
                                                                                                                               000:0230:5
                                                                                                                               003:0232:4
                                                                                                                               005:0250:3
                                                                                                                               005:0230:3
 ENL:
                                                                                                           3
                                                                                                                               005:0290:3
 IF CHANNELS LSS 15 THEN GO TO FINI;
                                                                                                                               nn5:0230:5
                                                                                                                               nn5:0250:5
 RAVERAGE TOGETHER ALJACENT FREQUENCY BANDS.
                                                                                                                               005:0230:5
                                                                                                                               nn5: 025E: 3
 1::1:
 IF LAV THEN BEGIN
     X:=1./FSTEP; Y:=-X;
DO BEGIN AVEPER[J]:=1./FREU[J]; PS[J]:=* * X; PSA[1,J]:=* * X;
PSA[2,J]:=* * X; PSA[3,J]:=* * X; PSA[4,J]:=* * X;
CSN[J]:=* * X; USN[J]:=* * X; CSW[J]:=* * Y;
OSW[J]:=* * Y; CNW[J]:=* * Y; QNW[J]:=* * Y;
                                                                                                                                005:023F:2
                                                                                                                                005:02A3:0
                                                                                                                                005:02AA:0
                                                                                                                                005:0280:5
                                                                                                                                005:0286:2
                                                                                                                                005:0288:5
     END UNTIL J: # +1 GEG 65;
```

```
005:02bE:1
                                                                            ENLPT:=128:
                                                                                                                                  J:=65;
        VPLAVEFQ:=1;
                                                                                                                                                                                                                                                            065:0200:3
5
                                                                                                                                                                                                                                                            005:0200:3
LOGPER: VALAVEFU: * * 2;
                                                                                                                                                                                                                                                            005:0202:0
        DO BEGIN
                                                                                                                                                                                                                                                            005:0222:7
                        K:=1;
                                                                                                                                                                                                                                                            005:0202:4
                        EU BEGIN

FREJ[J]:=* + FREQ[J+K]; UMEG4[J]:=* + OMEG4[J+K];

PSA[J]:=* + PS[J+K]; PSA[Z,J]:=* + PSA[Z,J]:=*

PSA[J,J]:=* + PSA[J,J+K]; PSA[Z,J]:=* + PSA[Z,J]:=*

CSN[J]:=* + CSN[J+K]; PSA[4,J]:=* + PSA[4,J]:=*

CSN[J]:=* + CSN[J+K]; USN[J]:=* + QSN[J+K];

CSN[J]:=* + CSN[J+K]; USN[J]:=* + QSN[J+K];
                        LO BEGIN
                                                                                                                                                                                                                                                            005:0202:4
005:0208:0
                                                                                                            PSA[2,J]:=* + PSA[2,J+K];

PSA[4,J]:=* + PSA[4,J+K];

USN[J]:=* + USN[J+F];

USN[J]:=* + USN[J+K];

UNN[J]:=* + UNN[J+K];

KONE[J]:=* + KONE[J+K];
                                                                                                                                                                                                                                                            005:02CA:4
                                                                                                                                                                                                                                                            005:0201:3
                                                                                                                                                                                                                                                            NN5: N2Eb: N
                                                                                                                                                                                                                                                            005:0210:2
                         CNw[J]:=* + CNw[J+K];
JACOB[J]:=* + JACOB[J+K];
                                                                                                                                                                                                                                                            005:02.4:4
                                                                                                                                                                                                                                                            065:02E8:0
                                                                                                                                                                                                                                                            AN5:02ED:2
                         <T+0[]:=* + KTW0[J+K];
                                                                                                                                                                                                                                                            005:02FG:0
                         END UNTIL K:=*+1 GEC VALAVETO:
                                                                                                                                                                                                                                                            005:02F2:4
                                                                                                                                                                                                                                                            nn5:02F2:2
                                                                                 x:=1./(VALAVEFU*FSTEP);
         Z:=1./VALAVEFU:
                                                                                                                                                                                                                                                            065:0218:3
         PEGIN
                                                                                                                                                                                                                                                            005:02:8:3
         ADTE: THE "NATURAL" RIGHT-HANDED BUDY COURDINATES ARE NORTH & SEST,
        BUT EAST AND IGRIH ARE MORE CONVENTIONAL; SO, SINCE E. SLOPE=-A.SLOPE FOR NORMALIZATION MULTIPLY ALL CROSS SPECTRA INVOLVING W. SLOPE BY Y = -X OR EY Z IF ONLY AVERAGING IS DONE.

FREQ[J]:=* * Z; OMEG4[J]:=* * Z; PS[J]:=* * X;
                                                                                                                                                                                                                                                             005:02:8:3
                                                                                                                                                                                                                                                             nn5:n218:3
                                                                                                                                                                                                                                                             005:0216:3
                                                                                OMEG4[J]:=* * Z; PSA[3,J]:=* * X; PSA[3,J]:=* * X; CSN[J]:=* * X; OSN[J]:=* * X; OSN[J]:=* * X; OSN[J]:=* * X; ONN[J]:=* * X; ONN[J]:=* * X; ONN[J]:=* * X; ONN[J]:=* * Z;
                                                                                                                                                                                                                                                            005:0418:3
                         PSA[1,]]:= * X;
PSA[4,J]:= * A X;
CSA[J]:= * A Y;
                                                                                                                                                                                                                                                            nas: azfe: 1
                                                                                                                                                                                                                                                            005:0374:4
                                                                                                                                                                                                                                                             005:0374:4
                         JACOB[J]:= * * Z:
                                                                                                                                                                                                                                                             005:0312:0
                                                                                                                                                                                                                                                             005:0317:3
         END:
                                                                                                                                                                                                                                                             005:0317:3
                                                                                                                                                                                                                      5
         AVEPEN[J]:=1./FKEU[J];
                                                                                                                                                                                                                                                             005:0318:0
         END UNTIL J: = + VALAVEFU GEO ENDPT;
                                                                                                                                                                                                                                                             005:0311:3
         ENDPT: = * * 2;
IF ENDPT LEV NM1 THEN GO TO LOOPER;
                                                                                                                                                                                                                                                             005:0310:3
                                                                                                                                                                                                                                                             005:031F:0
                                                                                                                                                                                                                                                             005:0320:4
                                                                                                                                                                                                                                                             005:0320:2
 END FLSE DO BEGIN
                                                                                                                                                                                                                                                             1105:0320:5
            K:=1;
                                                                                                                                                                                                                                                             005:0321:3
            DO BECIN
                         FREQ[J]:=A + FREQ[J+K]; OMEG4[J]:=A + OMEG4[J+K];
PS[J]:=A + PS[J+K];
PSA[1,J]:=A + PSA[1,J+K];
PSA[2,J]:=A + PSA[
                                                                                                                                                                                                                                                             005:0321:3
                                                                                                                                                                                                                                                             005:0326:5
                                                                                                              PSA[2,J]:=* + PSA[2,J+K];
                                                                                                                                                                                                                                                             005:0329:3
                                                                                                             PSA[4,J]:=* + PSA[4,J+K];
QSN[J]:=* + QSN[J+K];
QSW[J]:=* + QSW[J+K];
                                                                                                                                                                                                                                                              005:0321:5
                          CSN[J]:=* + CSN[J+K];
CSW[J]:=* + CSW[J+K];
                                                                                                                                                                                                                                                             nn5:0336:5
                                                                                                                                                                                                                                                              005:0330:1
                                                                                                              (NW[J]:=* + (NW[J+K];
                                                                                                                                                                                                                                                              005:0341:5
                          CNW[J]:= * + CN#[J+K];
                          JACOB[J]:=* + JACOP[J+K];
KIHJ[J]:=* + KIHJ[J+K];
                                                                                                                                                                                                                                                              005:0346:5
                                                                                                              KCNE[J]: # + KONE[J+K];
                                                                                                                                                                                                                                                              005:0342:1
                                                                                                                                                                                                                                                             005:034E:5
            END UNTIL X:= *+1 GEC AVEFQ:
                                                                                                                                                                                                                                                              nn5:0351:1
                                                                                                                                                                                                                                                              005:0351:1
                                                                                   X:=1./(AVEFO*FSTEP);
                                                                                                                                                                       Y:= -X:
                  L:=1./AVEFu:
                                                                                                                                                                                                                                                              005:0357:3
                          BEGIN
                                                                                                                                                                                                                                                              nn5:n357:3
                                                                                                                                                                                                                                                              na5:3350:0
                                                                                                                                                                                                                                                              nn5: 0363:5
                                                                                                                                                                                                                                                              005:0369:2
                                                                                                                                                                                                                                                             005:036E:5
                                                                                                                                                                                                                                                             005:03/4:2
```

```
003:0374:2
005:0378:0
AVE ER[ ! +( ] DIV AVEF() ]:=1./FREQ[J]; INI UNTIL J:=^+AVEF( CEQ N - 1;
                                                                                                  005:0374:2
                                                                                   3
                                                                                                  005:037A:5
      CALCULATE WAVE DIRECTION AND RMS BEAR WIDTH.
                                         PT:=55; END
ENOP1:=NM1; END;
IF LAV THEN HESIN VALAVEFY:=1; | LLSE BEGIN VALAVEFY:=AVEFY;
                                                                                                  003:037A:5
                                   ENDPT:=50;
                                                                                                  005:0370:1
                                                                                                  005:037F:4
                                                                                                  nn5:03/F:4
                                                                                                  005:0360:2
ADDIT: DO BEGIN
                                                                                                  005:0330:2
         015:0334:3
          234: = CNW [K];
                                                                                                  005:0388:5
         JACOBK:=JACOb[K];

IF (13 NED 0
                                                                                                  an5:0330:2
                                                     034:=QN#[K];
                                                                                                  005:0381:5
                                                                K22:=KTWU[K];
                                         K11:=KONE[K];
                                                                                                  005:0353:2
          IF (13 NEU ". THEN ZETA: #ARCTAN2( Q14 , -Q13) CLSE ZETA: #51GN(-Q14)*P1/2;
                                                                                                  005:0315:2
                                                                                                  nn5: n3 4C:1
          ZEIA:=* * 180./FI;
                                                                                                  075:033F:4
          ZETA IS THE DIRECTION OF PROPAGATION ART N-A COORDINATES.
ŧ
                                                                                                  n65:039F:4
          BETA IS THE DIRECTION FROM WHICH THE WAVES ARE COMMING DEG. T.
8
                                                                                                  nr5:n35F:4
          BETA[J]:=160. - ZETA;
                                                                                                  005:03A2:1
          K2:=(K1:=.04'2840996*(FSTEF*K)**2)**2;
                                                                                                  005:0346:4
          1 * PI**2/JEE = . 0402840395.
8
                                                                                                  005:03A6:4
          IF CIL NEQ P. THEN
                                                                                                  005:0347:2
          RK:=SQRT((C33 + C44)**2 + 4.*C34**2)/(K2*C11) ELSE RP:=0.;
                                                                                                  005:03AE:1
          nLL[J]:= hK:
          C:=(1. - RK)/(1. + KR); IF C LSS (. THEN C:=0.;
                                                                                                  nn5: N3AF: 3
                                                                                                  065:0315:0
          C:=2.*ARCTAN(SQRT(C));
                                                                                                  005:0333:2
          CREST[J]:=180. *C/PI;
                                                                                                  nn5:0380:2
      CALCULATE FOURIER COEFFICIENTS OF DIRECTION FOR EA. FREU.
*
                                                                                                  885:85:E
          DIRECTIONAL COEFFICIENTS ARE ART ANGLE ZETA NOT BETA.
                                                                                                  005:03:0:2
          A0[J]:=C11/P1;
          005:0300:2
                                                                                                  005:0307:5
                                                B2[J]:=2.*C34/(PI*K2);
                                                                                                  nn5:330n:5
                                                                                                  005:0306:5
          CALCULATE SPECTRAL MOMENTS AND RATIOS OF MOMENTS EIC.
4
          NZ=\0: #C11*JACOBK;
\01 :=\13*JACOBK/K11;
                                   1 THIS IS NOO.
1 THIS IS NOT (QSN).
                                                                                                  nno:n3bn:2
                                                                                                  nn5:0302:1
                                          THIS IS WIN (USE).
THIS IS WON (CO-EE).
THIS IS WON (CO-NN).
THIS IS NIL (CO-NE).
               := 14*JACOBK/K11;
                                                                                                  nn5:n3v4:1
          410
                                                                                                  NAS:0315:5
                : = C44 * JAC CBK / K22;
          620
               :=C33*JACOBK/K22;
                                                                                                  005:03.7:4
          NOZ
                                                                                                  005:0309:3
          N11
                :=C34*JACC3K/K22;
                                                                                                  035:030B:2
                                                                                                  005:031b:2
                                           1 (CO-SE) & NA6[J].
1 (CO-SN) & NA7[J].
          W12: = C14*JACGBK/K11;
          H21:=Cl34JACOBK/Kl1;
                                                                                                  nn5:1300:1
                                                                                                  005:63EF:0
                                           4 (LNE) & NA8[J].
          N22:=U34*JACOBK/K22;
                                                                                                  005:03E0:5
•
                                                                                                  065:03E0:5
          IF NZERO NEQ O. THEN ANGI[J]:=ARCTANZ( NO1 , N10 )
                                                                                                  075:0323:4
          ELSE ANG1[J]:=0.;
ANG1[J]:=* * 180./PI;
                                                                                                   005:03E6:0
                                                                                                   NN5:N3EB:2
          IF NZERO NEQ O. THEN
          ANG2{J}:=.5^ARCIAR2( 2.*N11 , (N2N - N02)) ELSE

ANG2{J}:=0.;

ANJ2{J}:=* * L30./PI;
                                                                                                   115:03EC:1
                                                                                                   005:0311:5
                                                                                                   nn5:n3F3:3
                                                                                                   065:03Fb:2
                                                                                                   005:03/8:2
          DENOM1:=N17442 + N01442;
                                                                                                   065:03FA:2
          IF DENOTE NEG O. THEN
                RNE#[J]:=(N10*(N2) - N02) + 2.*N01*N111/DE 10M1 ELSE
                                                                                                   005:03-8:0
```

```
กกระก414:5
กกระก4ก2:3
                 RNE#[J]:=0.;
                                                                                                              005:0412:3
          NN+[J]:=(2. + 4.*RNEW[J]/PI)/(1. - RNEW[J]/PI);
                                                                                                              nn5:040C:4
           DEHOM2:=SURICDENOM1);
                                                                                                              005:9470:4
           IF LENGP2 CTR O. AND NNN[J] NEQ O. THEN

XALPH[J]:=NZERO/(2.*PI*DENCM2) - (NNN[J]*2.)/NNN[J] ELSE
                                                                                                              005:04 OE:1
                                                                                                              nn5:0410:0
                 XAIPH[J]:= n.;
                                                                                                              005:0417:2
                                                                                                              005:0419:0
:
          nn5:0419:0
                                                                                                              nn5:041E:2
                                                                                                              005:0423:4
           IF WZERO ELL O. THEN BEGIN
                                                                                                              003:0423:4
           \Al[J]:=0.; \AZ[J]:=0.; \A3[J]:=1.; \A4[J]:=0.; \A5[J]:=0.; \A5[J]:=0.; \A6[J]:=0.;
                                                                                                              005:0424:5
                                                                                                              005:042A:4
           END FLST BEGIN
                                                                                                              065:042E:1
           NOTE: THE RATIO OF THE AVERAGE MOMENTS ARE COMPUTED, NOT THE
                                                                                                              005:042E:4
                                                                                                              005:0445:4
                  AVERAGE KATIO.
           NA1[J]:=*/hZLRO;
                                   NAZ[ ] := */NZEkO;
                                                                                                              005:042E:4
                                                           NA3[Jj:=*/NZERO;
           NA4[J]:= */NZEKO;
                                   NA5[J]:=*/NZEFG:
                                                                                                              005:0434:I
           NA6[J]:=4/NZERO;
                                  VA / [ ] ] : = 4 / NZ LRO;
                                                           NAB[J]:=*/NZERO;
                                                                                                              005:0437:5
                                                                                                              005:0432:2
           INU:
       END UNTIL K: = * + VALAVERQ GE, ENDPT;
                                                                                                              005:0430:2
                                                                                                              065:045F:5
                                                                                             3
       IF (LAV AND EMPPT EQL 65) THEN BEGIN

K:=ENLPT: VALAVEFQ:=* * 2; ENLPT:=128; END ELSE

IF LAV THEN BEGIN K:=ENDPT+1; VALAVEFQ:=* * 2; ENLPT:=* * 2;END;
                                                                                                              005:043F:5
                                                                                                              005:0441:4
                                                                                             3
                                                                                                              005:0445:0
                                                                                                              005:044A:4
       IF (LAV AND ENEPT LEG NM1) THEN GO TO AUDIE;
                                                                                                              nn5:n44C:3
4
                                                                                                              005:0446:3
                       *EST:=1;
       WHILE PVEPFA[K] GIR .984 LO BEGIN WEST:=*+PVEFQ; K:=*+1; A .985 SEC. FLRIOD WAVE HAS A WAVELENGTH EQL BUOY DIA.=> FT.
                                                                      K:=*+1; END;
                                                                                                              DG5: P4 4D: 5
                                                                                             3
                                                                                                              005:0454:0
       WEST: = NMI; % 10 PRINT OUT ALL VALUE UP TO NYQUIST.
                                                                                                              005:0454:0
Ł
                                                                                                              105:0455:0
                                                                                                              AA55:A
       IF TABLET THEN WRITE (PRINTER [SKIP 1]);
       IF TABLES THEN BEGIN
                                                                                                              005:0458:0
       WRITE(FRINTER, < "NORMALIZED AND AVERAGED CPOSS SPECTRA",/>);
                                                                                                              065:6458:5
                                  WRITE(PRINTER, FIG.); WRITE(PRINTER, FIL);
                                                                                                              005:0461:2
       wkITE(FRINTER, F9);
                                                                                                              005:0471:5
       WRITE(FRINTER, F15);
                                                                                                              005:0477:2
       K:=1;
If LAV then Begin
                                   VALAVEFQ:=1;
                                                                                                              nn5:n478:n
                                                           E.IDPT: = 65;
                                                                                                              005:047A:2
 TAL2:WRITE(FRINTER, F12, DO [2.4F14FREV[K], AVEPER[K],
             P3[<],P3A[1,<],P3A[3,K],P3A[4,K],C3N[K],U3N[K],C3W[K],J3A[K],
Chw[K],Chw[K],BETA[K],CREST[K]] UNTIL K:=*+VALAVEFU GEO
                                                                                                              005:0438:5
                                                                                                              nn5: n4 5E: 2
             EVEFT);
                                                                                                              005:04AA:1
       IF LND FT E(1 65 THEN BEGIN K:=65; VALAVEF(:=* * 2; ENDPT:=128; END ELSE BEGIN K:=ENDFT+1; VALAVEF(:=* * 2; ENDPT:=* * 2; END; IF ENDFT LE, ENT THEN GG TO TAB2;
                                                                                                              005:04 AF:1
                                                                                                              005:0423:4
                                                                                                              605:6428:3
                                                                                                              005:0469:5
                                                                                                              005:0439:5
       WRITE(FRINTER, F12, TO [x.*PI*FREQ[K], AVEFER[1 + (K LIV AVEFU)],
                                                                                                              005:04:9:5
             FS[K], PSF[1,K], PSA[3,K], PSA[4,K], CSF[K], QSN[K], CSW[K], QSW[K], CNW[K], DNW[K], BFTA[1 + (K DIV AVEFQ)], CREST[1+(K DIV AVEFQ)]
                                                                                                              005:04:9:4
                                                                                                              065:64 E1:2
                                                                                                              095:04E8:1
       UNTIL (:= * + AVEFO CEO WEST);
                                                                                                              005:04 F2:1
       LNU;
       IF ((TABLEZ AND TABLES) OR (TABLES AND TABLES)) THEN
                                                                                                              005:04r2:1
       maire(printea[Skir 1]);
                                                                                                              005:0464:0
```

```
005:04F9:4
005:04FB:0 56
       J:=1;
WHILE AVEPER[J] GTR TLIM DO J:=*+1;
WHILE PVEPER[K] GTR .985 DO K:=*+1;
                                                                                                                         005:04FE:3
                                                                                                                         005:0503:3
       IF TABLES THEN BEGIN
                                                                                                                         005:0514:2
                                                                                                      3
                                                    ARITE(PRINTER, F14):
       ARITE( >RINTER, F13, TLIM);
                                                                                                                         005:0517:4
       WRITE(FRINTER, F5);
                                                                                                                         005:0510:0
       IF (NUT LAV) THEN
       WRITE(FRINTER, F8, DO [J, AVEPER[J], An[J], Al[J], A2[J], b1[J], B2[J], BETA[J], CREST[J]] UNTIL J:=*+1 GEG K)
                                                                                                                         005:0510:2
                                                                                                                         005:(531:5
                                                                                                                         005:0530:4
                                                                                                                          005:0543:0
                                             ENDPT:=65;
    1AB3:WRITE(PRINTER, F8, D0 [J, AVEPER[J], AO[J], A1[J], A2[J], B1[J], B2[J], BETA[J], CREST[J]] UNTIL J:=*+VALAVEFQ GEW ENDPT);
IF ENDFT EUL 65 THEN BEGIN J:=L5; VALAVEFQ:=* * 2; ENDPT:=128;
           VALAVEFU:=1:
                                                                                                                         005:0544:3
                                                                                                                          005:0550:5
                                                                                                                         005:0569:4
                                                                                                                         005:056E:1
                                                                                                                          105:055E:1
                                VALAVEFU:=* * 2;
                                                                  ENDPT:=* * 2:
            J:=ENDP[+1;
                                                                                                                          005:0573:0
            IF ENTPI LEU NEL THEN GO TO TAB3:
                                                                        END:
                                                                                                                          005:0574:2
                                                                                                                          105:0574:2
SFOR TABLE 4 THERE IS AN UNCONDITIONAL PRINT.
                                                                                                                          005:0574:2
WRITE(PRINTER[SKIP 1]);
                                                                                                                          005:0573:3
                                       K:=1:
MRITE (PRINTER, F16):
                                                                                                                          065:057F:4
WHITE (FRINTER, FL7. DG [2.*PI*FREQ[K]. NAI[1+K DIV AVEFQ].
                                                                                                                          005: (5BE:4
            NA2[1+K DIV AVEFU].
            NAJ[1+K DIV AVEFO], NA4[1+K DIV AVEFO], NA5[1+K DIV AVEFO], ANG1[1+K DIV AVEFO], ANG2[1+K DIV AVEFO], RNEW[1+K DIV AVEFO],
                                                                                                                          005:0534:1
                                                                                                                         nn5:059C:4
                                                                                                                          005:0547:1
            RLU[I + K DIV AVEFQ].
                                                                                                                          005:05AA:4
            NNN[1+K DIV AVEFQ].XALPH[1+K DIV AVEFC]] UNTIL K:=*+AVEFQ
                                                                                                                          nn5:n582:2
            GEC NMI):
                                                                                                                          005:0538:4
                                                                                                                          005:0568:4
            TABLE 5 IS ALSO AN UNCONDITIONAL PRINT.
WHITE(PHINTEP[SKIP 1]);
WRITE(PHINTER, <"THESE MOMENT RATIOS SHOULD BE SMALL; NCHECK=",
"N(1) + N10 (SHOULD EQL 1.0).",/>);
                                                                                                                          A65:0528:4
                                                                                                                          005:0560:5
                                                                                                                          005:05BF:4
                                                                                                                          005:3503:2
            ARITE(PRINTER, F18): K:=1:
WRITE(PRINTER, F19, DO [2.*PI*FREQ[K], NA6[1+K DIV AVEFQ],
                                                                                                                          n05:0509:3
                                                                                                                          005:0508:4
                               VAT[1+K DIV AVEFJ], NAB[1+K DIV AVEFJ], NAB[1+K DIV AVEFJ]
                                                                                                                           005:05 [F:4
                                                                                                                           005:0514:4
            UNTIL K:= *+ AVEFO GEU NM1);
                                                                                                                           065-05 FB:4
1
                                                                                                                          005:35E0:4
        IF PUNCHES THEN BEGIN
                                                                                                                           P65:05EC:3
                                                                                                        3
                                                                                                                           095:05ED:1
        IF (NOT LAV) THEN'
                                                                                                                           005:05EL:3
        WRITE(FUNCHER, <8E10.2>, DO [CSN[J], QSN[J], CSW[J], QSW[J], CNW[J],
                   UNW[J].PS[J].FFEQ[J]] UNTIL J:= *+AVEFG GEQ HM1)
                                                                                                                          nri5:0602:2
                                                                                                                           A65: NoOB: 3
        FISH EEGIN
                                                                                                                           075:7611:1
                                                                                                        4
                                               ENDPT: = 65:
            VALAVEFy:=1;
 FUN]:WRITE(PUNCHER, < SEIO...>, DO [CSN[J], QSN[J], CSW[J], QSW[J], CNW[J],

__NN[J], PS[J], FREQ[J]] UNTIL J:= * * VALAVEFQ GEQ ENDPT);

IF ENDFT ECL &5 THEN REGIN J:= 65; VALAVEFQ:= * * 2; ENDPT:= 128;
                                                                                                                           005:0612:4
                                                                                                                           105:0627:2
                                                                                                                           005:0635:4
                                                                                                                           005:06 JA:1
                                                                                                        5
        END ELSE BEGIN
                                                                                                                           005:053A:4
                                                                 ENDPT:=* * 4:
                                 VALAVEFU:=* * 2;
            J:=ENOPI+1:
        - 1F ENDPT LEG NAL THEN 30 TO PUVI:
END: 1F PUNCHPS THEN BEGIN
IF (NOT LAV) THEN BEGIN
                                                                                                                           175:003F:7
                                                                         END;
                                                                                                                           005:0640:2
                                                                                                                           005:06:1:1
        J:=1;WRITE(FUNCHER,<6E10.2>,DO PSA(1,J) UNTIL J:=*+AVEFQ GEC NM1);
J:=1;WRITE(FUNCHER,<8E10.2>,DO PSA(3,J) UNTIL J:=*+AVEFQ GEQ NM1);
J:=1;WRITE(FUNCHER,<8E10.2>,DO PSA(4,J) UNTIL J:=*+AVEFQ GEQ NM1);
                                                                                                                           005:0642:0
                                                                                                                           105:06:4:1
                                                                                                                           N15:0650:4
                                                                                                                           005:06/9:1
         END ELSE BEGIN FOR <:=1, 3, 4
VALAVEF(:=1; ENDFT:=65;
                                                              DO BEGIN
                                                                                                                           nn5:0680:2
                                                                                                         5
                                                                                                                           nn5:6662:3
 FUNZ: WRITE (FUNCHER, < 8F10. Z>, DC PSk[K, J] UNTIL J: =*+VALAVEFC GEQ ENDPT);
         IF FIDET EUL 55 THEN BEGIN J:=65; VALAVEFD:=* * 2; ENDPT:=128; ENL ELSE BEGIN
                                                                                                                           005:0654:4
                                                                                                                           0015:0659:1
                                                                                                                            075:0639:4
         J:=ENDPT+1: VALAVEFJ:=* * 2;
IF ENLFT LF, MM1 THEN GO TO PUR2;
ENL: IF PUNCHUS THEN BEGIN
                                                                   ENDPT:=* * 2;
                                                                                           END:
                                                                                                         6
                                                                                                                            005:065E:0
                                                                         ENL:
                                                                                          END:
                                                                                                                            005:06A2:3
                                                                                                                            005:0643:2
         IF (NOT LAV) THEN BEGIN
                                                                                                                            DAS: 0644:1
         K:= WM1 DIV AVEFO:
         J:=[; ARITE(PUNCHER, < BEIO. 2>, DO [FREQ[1+(J-1)*AVEFJ], BETA[J],
CREST[J], An[J], Al[J], A2[J], B1[J], B2[J]] UNTIL J:=*+1 GLG K);
                                                                                                                            005:0645:4
                                                                                                                            005:0634:2
                                                                                                                            Ons: Poca: n
         ENE ELSE BEGIN
                                                                                                                            nn5:(160A:3
             VALAVEFJ:#1:
                                               FNuPT:=65:
  PURS:WRITE(FUNCHER, < EE10.2>, LO [FREQ[J], BETA[J], CALLT[J], AU[J], AI[J], AZ[J], BI[J], BZ[J]] UNTIL J:= A+VALAVEFQ GEQ
                                                                                                                            005:06 CC: 4
                                                                                                                            005:0619:5
                                                                                                                            005:06EA:3
                                                                                                                            005:05EF:4
         IF ENDPT EQL 65 THEN BEGIN J:=65: VALAVEFQ:=* * 2: ENDPT:=128;
                                                                                                                            005:0614:1
         END ELSE BEGIN
                                                                                                                            005:06F4:4
                                                                    ENDPT: = * * 2: END;
                                  VALAVETU:=* * 2:
             J:=ENLPT+1:
                                                                                                                            005:0619:0
         IF ENEPT LEG NMI THEN GO TO PUN3;
                                                                    END:
                                                                                                                            005:06FR:2
         END:
                                                                                                                            005:06FA:2
                           & END OF MAIN BLOCK.
   FINI:ENL:
                                                                                                             BLOCK(OAS) IS AGEC LONG
                                                                                                         STACKCODE IS SEGMENT 00019
                                                                                                        STACKCUDE(019) IS OOSF LONG
                                                                                                                           002:0077:5
  vD.
                                                                                                             BLOCK(002) IS 0094 LONG
DATA IS 0060 LONG
```

COMPONENTS

The following is a list of the major components of the buoy, procurement source, and approximate cost in 1972.

Battery: Lead-Acid 12 volts, 20 ampere hour

\$40 ea

capacity (6 required)

Model GC12200

Globe Battery Division

P.O. Box 591

Milwaukee, Wisconsin 53201

Inverter: 12 VDC to 115 VAC 400 Hz 100 watt capacity \$250

Model 12400-12(w/input-output filters)

Nova Electric Manufacturing Co.

263 Hillside Ave.

Nutley, New Jersey 07100

3. Radio Transmitter: Citizen band (Marine data channels)

\$150

500 mw, modulated

Model BT-109 (modified)

Ocean Applied Research Corp.

10475 Roselle Street

San Diego, California 92121

4. Visual Beacon: Flashing Xenon Lamp

\$200

0.5 flashes/sec, self contained batteries

Model

Ocean Applied Research Corp.

10475 Roselle Street

San Diego, California 92121

5. Vertical Gyro/Accelerometer Assy: Includes Honeywell

Model GG326Cl Quartz fiber accelerometer

mounted on inner gimbal of Honeywell Model

JG7044A45 vertical accelerometer

\$6000

Model GG1134AA01

Honeywell Inc. Aerospace Division Dept 691 2600 Ridgeway Rd.

Minneapolis, Minnesota 55413

6. Directional Gyroscope: North seeking

\$700

Model DG04-0122-1

Humphrey, Inc.

9212 Balboa St.

San Diego, California

7. Data Recorder System

\$4000

A. Data Recorder/Logic Assembly

Model 10015

Monitor Labs, Inc.

10451 Roselle St.

San Diego, California 92121

B. Incremental Digital Tape Recorder

\$2500

Model 1387

Precision Instrument Co.

3170 Porter Drive

Palo Alto, California

C. Low-Power Analog-to-Digital Converter \$900

Model ADC-12QL

Analog Devices, Inc.

P.O. Box 280

Norwood, Mass. 02062

D. Low-drift, low-power operational amplifier \$50

Model 153J

Analog Devices, Inc.

P.O. Box 280

Norwood, Mass. 02062

8. Buoy Hull Assy \$10,000

No Part Number

Honeywell Marine Systems Center

5303 Shilshole Ave., N.W.

Seattle, Washington 98107

9. Radio Transmitter Antenna: 3 needed \$75 ea

Model AW257

Ocean Applied Research Corp.

10475 Roselle St.

San Diego, Ca. 92121